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PERFORMANCE OF COULTERS FOR MINIMUM TILLAGE SEEDING

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Performance of Coulters for Minimum Tillage Seeding" submitted by Krishan Kumar Chawla in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

In recent years, minimum-tillage has become increasingly popular due to the time and labour saving aspects of this cultural method. In addition, preservation of soil structure, reduction of soil loss due to water and wind erosion are some of the other advantages associated with the minimum-tillage operation.

One of the major problems in minimum (zero) - tillage facing the agricultural engineer is to design a machine to obtain the proper seeding depth. The objective of the present study was to determine the most suitable coulter for minimum tillage field conditions. The criteria employed for evaluating the performance of coulters were depth/load relationship, maximum obtainable depth and operational conveniences.

For the present study, a "Kirschmann" double disk seed drill with coulter attachment was used. From a priori operational considerations such as power requirements, accumulation of straw etc/. a freely rotating disk coulter was selected for further investigation. Three test fields were selected to represent the minimum tillage field conditions viz. fallow field of density 66.7 lb/ft^3, with and without straw; fallow field of density 74.5 lb/ft^3, with and without straw; and stubble field of density 57.2 lb/ft^3.

Depth/load relationships for five coulters sized 9 1/2 in. to 18 in. diameter and a double disk of 13 1/2 in. diameter were obtained for all five field conditions mentioned above. The load measurements were made with the help of a strain-gauged transducer and an ultra-violet recorder. The corresponding depth readings were taken with a tape measure. Soil physical properties were also measured to characterize the soil condition.

The larger sized coulters were found to give significantly better performance at a given load particularly on the strawed and stubbled fields. Furthermore, greater loads could be applied on the larger coulters and thus greater depth could be obtained. The performance of the 17 inch notched coulter was distinctly superior particularly on the strawed and stubbled fields. Due to operational difficulties with large coulters, a notched coulter of 14 - 15 inch diameter would be the most suitable for use in minimum-tillage seeding.

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Dedicated to

Bharti and Rupesh

Chapter 1

INTRODUCTION

1.1 A historical background of tillage associated with planting.

In an endeavour to increase agricultural productivity of farmers, modern society has built and promoted the use of increasingly large farm machinery. The advantages accrued from the use of these big machines are chiefly that of low labour requirements and time savings during the planting season. However, there are certain dysfunctional consequences of heavy tractor loads on the soil structure. One important dysfunctional consequence is the "soil compaction" caused by the forces applied by tractor and implement wheels on the soil structure.

Compaction of agricultural soils is by no means a simple phenomenon; it is significantly interrelated with most of the recognized physical, chemical and biological properties of soils. It is also associated with certain environmental factors such as climate, weather, tillage and agronomic treatments and crop use. The state of compaction of a soil largely influences seed germination, seeding emergence, and root growth. In fact, it influences each and every phase of crop growth and production. As such, the design, selection, and management of tillage equipment and cropping systems must be so directed as to produce the optimum state of compaction of soil throughout the period of crop production. Reducing the number of trips over the field in preparing a seedbed reduces compaction and saves time, labour and production cost.

Zero-tillage drilling of seed is currently of interest in many areas. This type of seeding is defined here as the seeding of a crop

using a drill but without complete tillage of soil to prepare a seedbed. Tillage is confined to the seed row area and may be provided by a rolling coulter, a knife type opener, or a hoe type opener. In real terms, broadcast seeding is the only zero-tillage seeding. Herein, it may be appropriate to mention that the term 'zero-tillage' is conceptually weak for it indicates 'no operation' of the type mentioned above. As such, it would be more appropriate to use the term 'minimum-tillage' rather than 'zero-tillage' indicating some prior operation to seeding.

1.2 The objective of the present study.

One of the major problems in minimum (zero) tillage that agricultural engineers are facing is to place the seed at the proper depth. To make the minimum-tillage system more scientific and exact, it is of real importance to find out the degree of force required to obtain certain depths of penetration of freely rotating disk coulters and the effect of physical properties of soil as well as the effect of trash on coulter penetration. It may be mentioned that the freely rotating disk coulter was used because of specific operational advantages over the other types of coulters. The disk coulter requires less power for its movement and is not plagued by straw or trash left over from the previous crop. Rather, the straw is cut and kept evenly strewn in the field.

For the purpose of this experiment, a "Kirschmann" double disk seed drill with coulter attachment was used for detailed study, particularly to find the depth-load relationship for different sizes of coulters. The soil condition was characterized by measuring the bulk density, moisture content, shear strength, penetrometer resistance, oxygen diffusion rate and the amount of straw.

Chapter 2

REVIEW OF LITERATURE

Minimum-tillage is becoming increasingly popular in many parts of the world. The main idea behind this new method has been to tackle the problem of soil compaction and also to save labour and time by reducing the number of trips over the field. Many investigators have demonstrated that the method of minimum-tillage is superior in many ways to the old conventional method of tilling the soil.

The minimum-tillage method, however, brought many new problems in its trail. One of the important problems was to design new seeding equipment to suit the new method. Another important problem that arose out of this method was to control weeds. However, this problem was eliminated by the use of herbicides although the cost may be prohibitive. The literature that follows relates to the research conducted on minimum-tillage and is divided into three parts:

a. Literature on minimum-tillage;

b. Literature on seeding mechanisms; and

c. Literature on furrow openers.

2.1 Minimum-tillage.

Shanholtz and Lillard (22) made a comparative study of no-tillage versus conventional tillage for plant available soil water, soil erosion, and yield. They found out that the no-tillage system promoted more efficient use of water by plants and reduced the erosion hazard. This happened because of the crop residue which was left on the surface unlike the conventional tillage system where the crop residue from the preceeding crop was turnplowed to a depth of 7 inches

during the growing season. Comparing the grain yields for corn grown under the two systems, the authors found the yield from the no-tillage system higher than the yield from the conventional tillage during the years 1966 and 1967.

Somewhat similar studies have been conducted by Jamieson (10), Mannering and Meyer (17), and Laws (13). Jamieson found that in the no-tillage method large amounts of residue were left on the soil surface. This reduced water erosion by over 90 percent and eliminated wind erosion almost completely. Mannering and Meyer found that whereas 500 lb. of straw per acre reduced soil loss by approximately 75 percent, 4000 lb. of straw per acre reduced soil loss to zero (given 6.25 inches of water applied at 2.5 in. per hour). Laws found that 3700 lb. of residue per acre were needed to maintain the soil in place.

Swamy Rao et al (26) compared the effect of minimum-tillage versus conventional tillage on soil physical properties and crop response. The tillage study was conducted on two typical types of soil and the results were as follows:

1. Minimum-tillage resulted in the following improved soil physical conditions:
   a. Higher rate of infiltration;
   b. Less soil resistance to penetration;
   c. Lower bulk density;
   d. Less soil compaction due to tractor and implement traffic.
2. These soil physical properties affected the crop in the following ways:

a. Less weed population;

b. Less plant mortality due to cultivation;

c. More root growth;

d. Taller corn;

e. Less stalk population;

f. Fewer lodged stalks at harvest;

g. Less corn loss in harvest;

h. Same yield as conventional-tillage at the existing stalk population.

3. The effect of minimum-tillage on the physical condition of the soil was more evident by the measurement of infiltration rate and soil resistance to penetration than by bulk density, soil moisture, and clod size measurements.

4. Minimum-tillage appeared to be better suited to coarse and medium textured soil types than to the more plastic soils with a high clay content.

5. Minimum-tillage tended to produce an uneven rate of planting of corn, and uneven germination, especially on soils with a higher clay content.

6. Minimum-tillage resulted in a saving of machine time.

Triplett et al (27) studied the effect of corn stover mulch on no-tillage corn yield and water infiltration. Corn was grown for three years on Wooster silt loam. Treatments included conventional preplant tillage (plowing, disking) and no preplant tillage with three corn stover residue levels, 5% cover (stover removed), 45% cover (stover left in place), and 70% cover (double level of stover). Except for the

first year when the tilled plots were not cultivated, grain yield with 45% cover (6,170 kg/ha) equalled the tilled check (5,970 kg/ha). Yields of treatments with 5% cover were significantly lower (4,770 kg/ha) than the tilled treatment and significantly higher with 70% cover (6,625 kg/ha). Soil moisture determined with gypsum blocks during the last two years was greater with increasing amounts of soil cover during the growing season. At the end of the third year, water infiltration was significantly greater with 70% cover than for the other treatments. Results from the experiments indicated that mulch protection which may be readily available from previous crop residues is necessary to maintain no-tillage corn yields on this and similar areas of Wooster silt loam. The beneficial effects of the mulch seem to be associated with increased soil moisture.

Somewhat similar work was done by Jones et al (11) who studied the effect of tillage, no-tillage, and mulch on soil water and plant growth. Seedbeds for corn were prepared by both conventional tillage and the no-tillage method, each with and without surface mulches. The mulches consisted of killed grass sod on the no-tillage plots and straw applied to plots with conventional tillage. No-tillage plots without a mulch were obtained by removing the killed sod. Mulched treatments, whether of undisturbed killed sod on the no-tillage plots or of straw on conventional plots, gave the lowest value of runoff and the highest values for soil water content and yield of corn. Soil water conserved by the mulches was reflected in an average grain yield increase of 1,932 kg/ha. Differences in total soil water among treatments were significant to a depth of 30 cm. The effect of tillage was minor, but the data indicated the value of the killed sod mulch in the no-tillage

system.

However, Van Doren (29) cautioned against blind faith in the no-tillage system. He found that no-tillage would not necessarily lead to higher yield. Van Doren demonstrated that no-tillage corn produced yields similar to conventional tillage with about 50% residue cover measured at harvest. With greater mulch cover, no-tillage yields were higher. No-tillage treatments were very sensitive to both previous crop and residue management. It gave the best results on sod with residues left on the soil surface and gave the worst results following silage corn.

A six-year study was made by Shear and Moschler (23) on continuous corn by the no-tillage and conventional tillage methods. Corn was grown on a loam soil on the same plots annually for a period of six years, comparing no-tillage, tillage in alternate years, and conventional tillage. An equal annual application of phosphate mixed in the tilled soil and applied to the surface of untilled soil resulted in more available phosphorus accumulation in the upper 5 cm. of the untilled soil. The total amount of available phosphorus for the upper 20 cm. of soil was greater in untilled soil despite the fact that available phosphorus was lower than in tilled soil in two of the 5 cm. increments below the surface layer. Potassium availability was not affected by tillage or method of application. Soil compaction after six years as based on bulk density showed no difference related to tillage. The maintenance of high yields of corn in successive years without tillage was shown. There was no benefit from tillage in alternate years as compared with no-tillage. An average increase in corn grain yields and equal or better stover yields from no-tillage as compared with

conventional tillage was found. The need for more frequent liming with the no-tillage method was demonstrated.

Siemens et al (24) found that there was no significant difference in total soil fertility with different tillage systems. In this study, five different tillage treatments were used and samples were analysed for soil acidity (pH), phosphorus, and potassium.

William (31), and Vincent (30) have found that only 20% of the surface area near the seed (row zone) has a significant effect on germination and early growth. The remaining 80% of the soil between the rows (inter-row zone) influences the penetration of rainfall and, possibly erosion. It has been shown that when this 80% of the soil surface is tilled as if it were a seedbed, water infiltration is reduced and erosion increased. For the best soil conditions, the area around the seed and the area between the rows should be tilled differently. Further, it was found by William that properly tilled soil in the same row zone should have a range of sizes of soil particles with perhaps an average size of less than one-quarter inch in diameter.

In 1969 Ford (9) of Chipman Chemicals Company reported on tests in Western Canada in which zero-tillage seeding was compared to conventional methods. Increased yields were obtained in certain areas however, the cost of the chemicals needed for weed control greatly exceeded the benefits gained from zero-tillage seeding.

Some very useful work on no-tillage systems is in progress in some of the Canadian research institutions. The University of Manitoba (32) is actively engaged in conducting research on no-tillage with three

different types of soil (sandy loam, loam and clay). In 1969-71 four crops were grown following a rotation of wheat, flax, barley and rape. The data collected during these years indicated that wheat, flax and rape seed could be grown successfully under zero-tillage condition. No problems were encountered in drilling directly into the stubble with a Kirschmann triple disk drill. It was also found out that zero-tillage could lead to reduced weed population and improved seedbed for small seeded crops.

The University of Saskatchewan also started a zero-tillage project in 1968 (8). Two types of seed drills, the Allis Chalmers "No-till" and the disker were compared on stubble land for seeding wheat. The results indicated that the disker was a superior seeding implement as compared with A.C. "No-till" drill when no fertilizer was used. However, the machines were found to be nearly equal when fertilizer was used.

At the University of Alberta, Bentley et al (4) have established a zero-tillage project which has field scale plots at three locations to compare zero, minimum and normal tillage under two cropping systems - continuous barley and alternate fallow-barley with three seeding techniques. On one location the triple disk, hoe drill, and disker were used and on the other two locations the double disk drill was used instead of the disker. Some experiments are also being conducted on small plots to study the fertility effects of zero and other tillage treatments.

2.2 Seeding mechanisms.

Triplett et al (28) tested the performance of two experimental

planters - "Grassland planter" assembled by John Deere Company and "Modified till planter" previously developed by International Harvester Company in 1950. The grassland planter consisted of a rolling coulter to cut the surface residues and a hollow chisel through which seed and fertilizer were dropped through separate openings. Semi-pneumatic press wheels closed the slit formed by the chisel and helped to cover the seed. The modified till planter consisted of a 14-inch wide, flat sweep working below the surface and three wheels of a rotary hoe to manipulate the soil in front of a conventional planter with a sword type opener.

Corn emergence percentage as a function of tillage practices and planting tools was determined by Triplett et al in 1961 and 1962 on a Hoytville silty clay loam. The only experimental planter used at this site was the grassland planter. Three tillage treatments were compared as follows:

1. Spring plowed, disked twice-planted with conventional planter;
2. Fall plowed - planted with conventional planter;
3. Not plowed - planted with grassland planter.

Herbicides were used to control weeds in the unplowed plot. The grassland planter with but one exception provided equal or better emergence than the conventional planter on spring plowed ground. It produced an emergence comparable to the fall-plowed treatment in three of the four trials.

In 1962, Triplett et al compared the performance of these two experimental planters on Wooster silt loam. Corn was planted on an

area which had been in corn in 1961. Treatments included a plowed and disked check planted with a conventional planter. Three residue (zero, normal and double) treatments were used for each experimental planter. The emergence for the non-plowed treatments on Wooster loam was not decreased by residue treatment except for the till planter at the double residue level.

Jones et al (12) modified two conventional seed drills to save time and labour. Drill No. 1 consisted essentially of a conventional drill grain box suitably modified and mounted on a Ford-Ferguson tiller with seed and fertilizer tubes attached to each opener. During the experiment the machine was converted from a three-point tractor - mounted, lift type to a two-wheel trailing type with remote hydraulic control. The opener shanks were of the standard spring release type used on the Ford-Ferguson tillers. Rolling coulters with spring release were mounted in front of each opener. Press wheels were mounted behind each opener for part of the test. Since opener shanks were attached to a rigid tool bar, depth control on irregular land was unsatisfactory. Drill No. 2 was an experimental unit assembled by Deere and Company for use in these and similar studies. It consisted of a standard grain drill box mounted on a trailing type field cultivator with seed and fertilizer tubes attached to each opener. Rolling coulters were mounted in front of each opener. Each opener was individually mounted with provisions for spring pressure adjustment for uniformity of depth control. Provision was made for mounting press wheels when desired. The complete job of preparing the seedbed, sowing the seed and applying fertilizer in one operation saved 50 percent of time and power over

conventional methods.

A summary of research on seeding mechanisms in Canada was given by Anderson (2) in 1969. Equipment development work was being carried out at the Canada Department of Agriculture Research Station, Swift Current, Saskatchewan, to construct seeding equipment required for plot studies. The equipment was designed for placement studies with cereal grains, grasses, and fertilizers. Development work was also underway at the University of Manitoba on a special seeder for pelletized grain. The University of Guelph, Ontario, had organized seeder development work to seed grain into partly frozen soil. Further, machine development work on planters for minimum tillage planting of corn was carried out at Guelph. Planter components such as the proper furrow opener for seed and fertilizer placement, packers and mechanisms for overcoming plant residue clearance problems were involved in the studies.

2.3 Furrow Openers.

Engineering research on planters and seed drills have been concentrated on the effect of their components on the final plant stands. Lately basic studies have evaluated the effects of soil factors such as density, strength and moisture content on seed germination and plant emergence. So far, very little research has been done on planter and seed drill furrow openers.

The furrow opener is a very important unit of the drill. There are mainly two types of furrow openers that are used in the field (25):

1. Sliding furrow openers: These type of furrow openers slide through the pretilled soil surface.

A. Hoe furrow opener: This is an oval-shaped tube that comes to a point at the bottom and is wider at the top so that the seed tube will fit into it. The lower end - which goes through the soil - usually has a renewable and reversible shovel point.

B. Shoe or runner opener: This wedge-shaped runner will slide through some light trash in a well-prepared seedbed. It is for shallow plantings only and can be used with depth gauges. This type of furrow opener is commonly used on row-crop planters.

2. Rolling furrow openers: The rolling furrow openers are disks or coulters. These not only prepare a seed furrow but also cut trash and lumps and help prepare the seedbed.

A. Single disk furrow opener: The single-disk opener has the least draft. On most drills the cut or angle of each disk is fixed by the shape of the drawbar. On others, the cut can be changed. This opener is best on hard or stony soil and also where there is considerable sod and trash.

B. Double disk furrow opener: It consists of two flat disks, together at the front, open at the rear. The double disk opener is excellent where the soil is dry and tough on top, heavy and wet underneath. It is quite efficient in soil trashed with corn stalks.

Abernathy and Porterfield (1) studied the opener shape on furrow characteristics. Only runner-type openers were considered in this experiment. The openers were plane faced wedges with three

different included angles (15°, 30° and 60°) in the horizontal plane. For each wedge angle the faces were vertically inclined at three different angles (90°, 135° and 150°) measured from the direction of travel (figure 2.1). This made a total of nine openers. The maximum width of all openers was 3/4 in. A set of furrow bottom compaction wedges with vertical displacement of 1/8, 3/16 and 1/4 in. were also tested (figure 2.2). The test openers were pulled through prepared soil samples at a speed of five miles per hour and at a depth of 2 in. Drag and lift forces acting on the test openers were measured by strain gauge transducers.

The results of the experiment conducted by Abernathy and Poterfield showed that the depth of the disturbed soil zone or furrow was significantly greater when the vertical face angles of the openers were 150° than when they were 90°. Openers with wedge angles of 60° made deeper furrows than openers with smaller wedge angles. The side or boundary angle of the disturbed soil zone was greatest for 135° vertical angle openers, and it was not significantly affected by the wedge angle. Width of the disturbed soil zone was affected by both depth and side slope. Openers with face angles of 135° made wider furrows than openers with angles of 90° and 150°. Wedge angles had no significant effect on furrow width. The cross sectional furrow area was significantly greater for the openers with 135° vertical angles than for other openers. Wedge angles also significantly affected the furrow area; the 60° wedge angled openers produced larger furrow areas than openers with 15° wedge angles. Operating forces were least for openers with small vertical angles and small wedge angles. They also

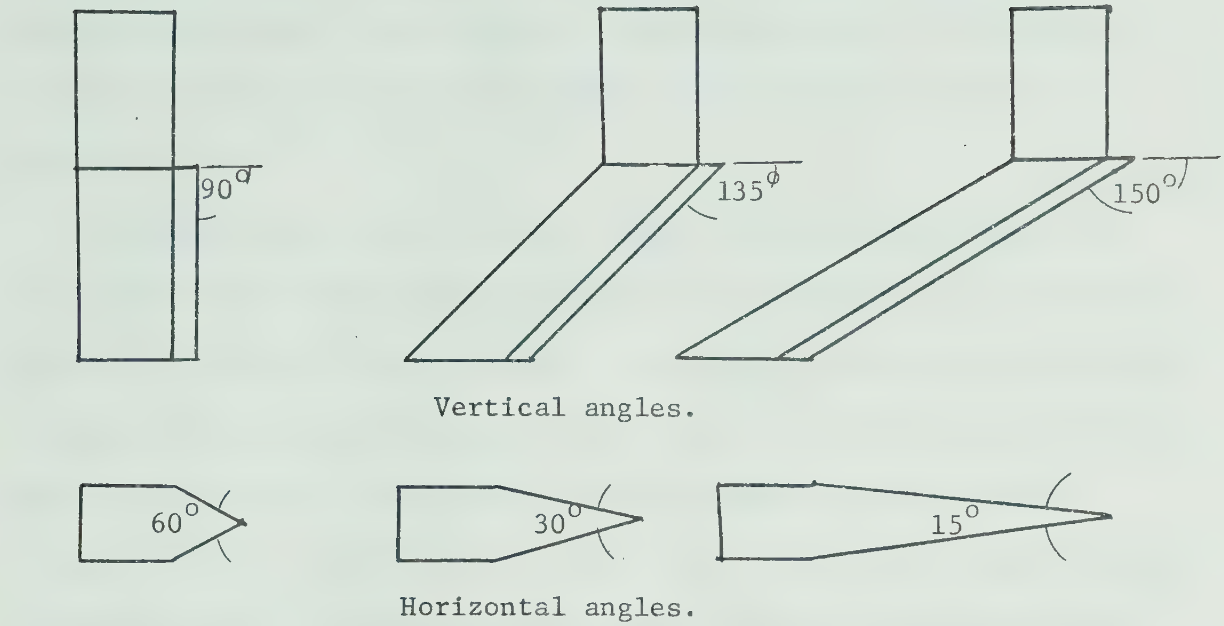


Figure 2.1: Vertical and horizontal angles used to describe test openers.

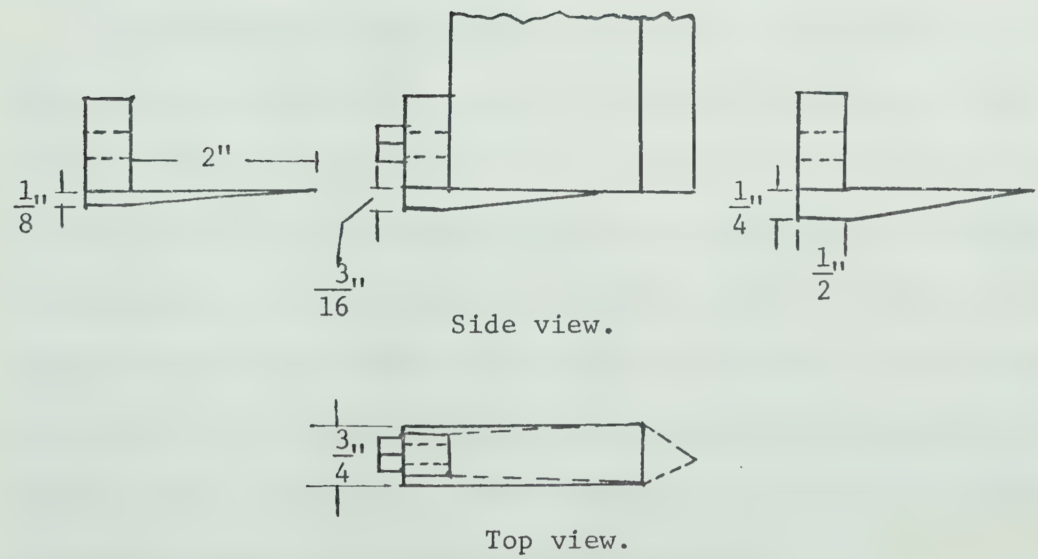


Figure 2.2: Furrow bottom compaction wedges.

concluded that soils with little cohesion can not be compacted by sliding wedge type furrow openers unless some method is devised to confine the soil. Such devices might include sliding shoe or low pressure tires.

Nabatyan (19) found that the double disk openers at speeds of 9 - 15 km/hr did not provide the specified agrotechnical requirements of uniform depth of seed coverage. In addition, this opener possessed a high draft and significant vertical force was necessary to maintain depth in the soil. A comparatively light drill at speeds above 9 km/hr was not able to provide this force. The author compared three different types of openers (double disk, spherical single disk and flat single disk) and concluded that the single flat disk opener mounted at an angle of attack of 10° and a tilt angle of 20° was the most expedient type of opener for high speed drills operating at speeds up to 15 km/hr.

A comparative study of powered coulters and freely rotating coulters was made by Rice and Gantt (20). The main objectives of their study were to find the force required to obtain penetration of both power driven and freely rotating coulters and measure the resulting power requirements. A 3-horsepower, variable speed, D.C. motor was used to operate the disk. A speed reduction of 42.31 to 1 was used between the motor and the disk and the power was supplied to the motor from a 10-kilowatt D.C. generator. These tests were conducted on Cecil sandy loam soil covered with coastal Bermuda grass.

The results of Rice and Gantt given in table 2.1 showed that forces required for penetration by smooth and cutaway disk coulters were greatly reduced when the disk coulters were driven in the direction

TABLE 2.1 FORCE AND POWER REQUIREMENTS FOR THE DISK COULTER.

Treatment	Smooth	Cutaway
1. Free rolling disk*		
Drawbar horsepower	2.78	2.56
Disk pressure, lbs.	812.00	861.00**
2. Forward rotation. 50 rpm		
Drawbar horsepower	-0.6	-0.03
Horsepower to rotate disk	3.71	3.16
Disk pressure, lbs.	853.0	816.0
3. Forward rotation. 60 rpm		
Drawbar horsepower	-0.52	-0.27
Horsepower to rotate disk	4.83	4.29
Disk pressure, lbs.	817.0	846.0
4. Reverse rotation. 43 rpm		
Drawbar horsepower	4.5	3.6
Horsepower to rotate disk	3.82	3.25
Disk pressure, lbs.	339.0	181.0
5. Reverse rotation. 53 rpm		
Drawbar horsepower	4.1	3.1
Horsepower to rotate disks	4.17	3.96
Disk pressure, lbs.	333.0	146.0
6. Reverse rotation. 63 rpm		
Drawbar horsepower	3.6	3.0
Horsepower to rotate disk	4.84	5.18
Disk pressure, lbs.	217.0	88.0

* Free-rolling disk speed was approximately 32 rpm for smooth and 43 rpm for cutway disk at approximately 2 miles/hr travel speed.

** Pressure gage would not register more than 861.0 lbs.

reverse to that of free rolling. The horsepower required to rotate the disk coulter was about the same for both directions for the same speed but the total of drawbar plus rotation-horsepower was greater for the reverse direction of rotation.

The curves in figures 2.3 and 2.4 as plotted by Rice and Gantt show the relation between disk pressure, horsepower, speed of rotation and the direction of rotation of the disk coulters. The dashed lines represent assumed paths of the curves, and show the areas where more information is needed. The results show that the treatment with the cutaway disk coulter, power driven in the reverse direction, was significantly better than the other treatments for obtaining penetration forces. The rotation of the powered disk coulter in the reverse direction reduced the force required for penetration by 79% and increased the horsepower requirement by 168%.

Lynbushko (16) conducted investigations on disk and runner boot openers for row seeding. Disk openers were adjusted at a depth of 8 cm and runner boot openers to a depth of 6 cm. Tests were conducted at forward speeds of 8, 12 and 16 km/hr. The investigation showed that during increased speeds (up to 12 km/hr) on well prepared soil, uniform depth of coverage of the seed did not decrease significantly. Further increases in speed up to 16 km/hr rapidly decreased the quality of seeding.

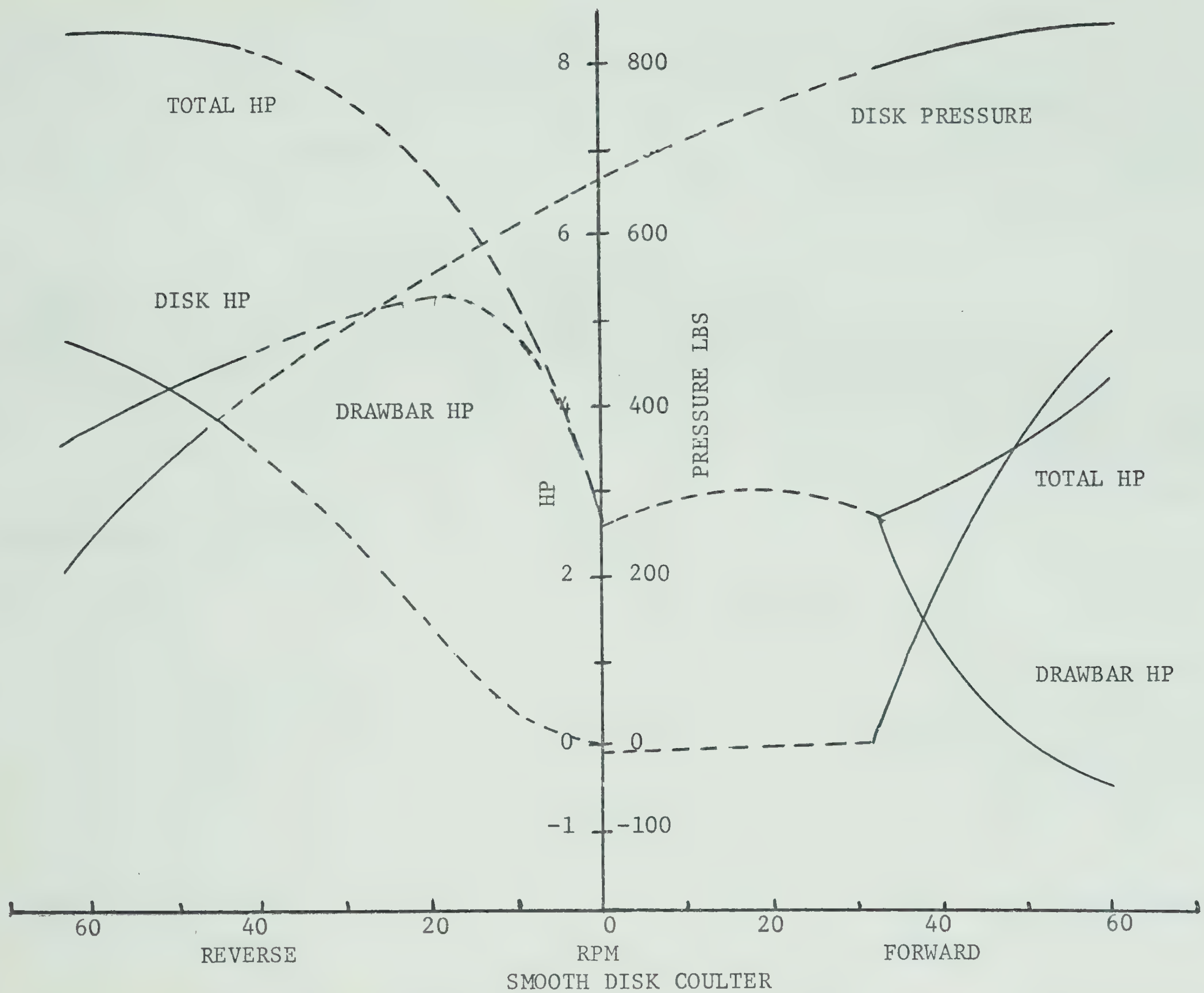


Figure 2.3: Relation between disk pressure, horsepower, speed of rotation, and direction of rotation of smooth disk coulter.

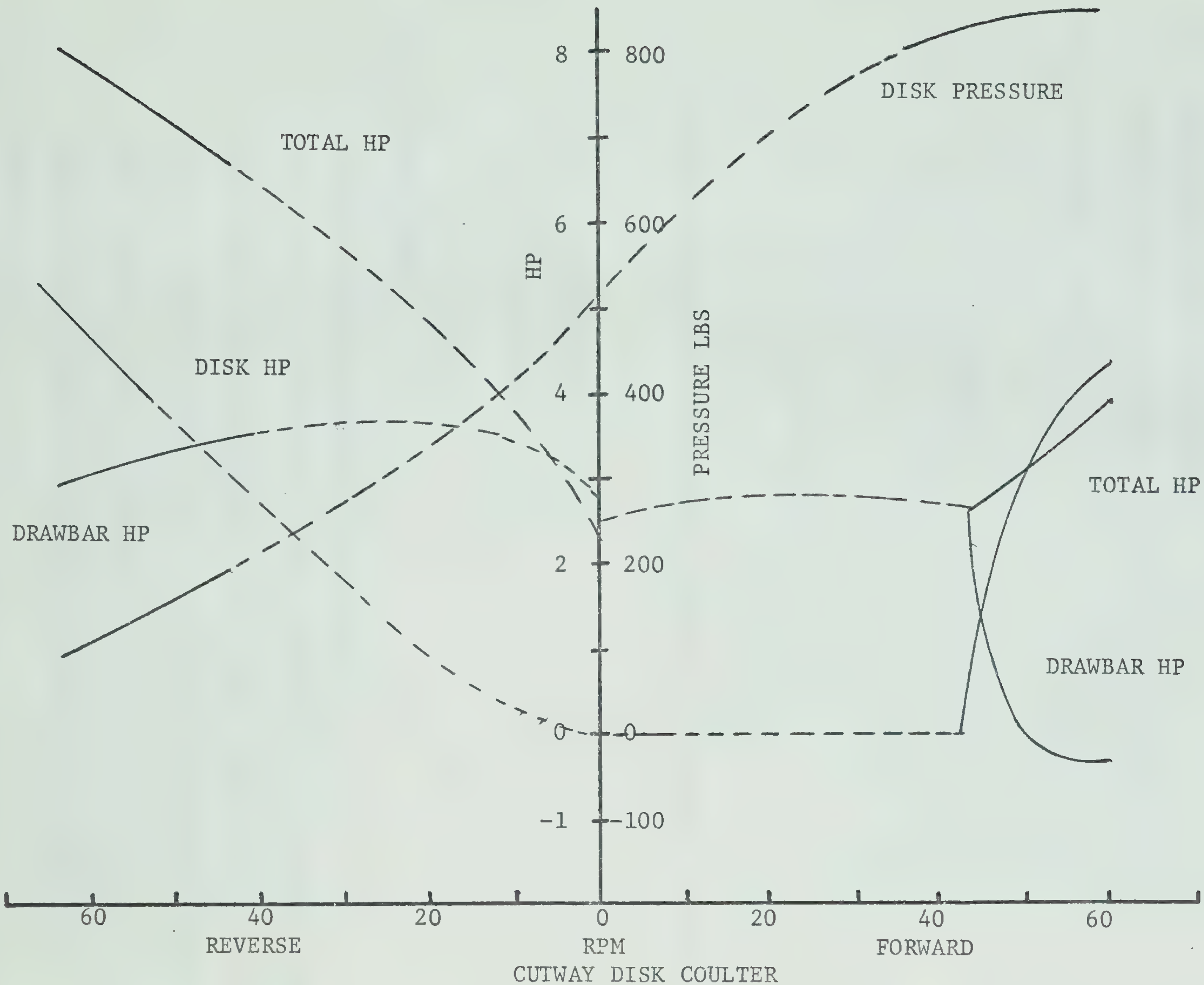


Figure 2.4: Relation between disk pressure, horsepower, speed of rotation, and direction of rotation of cutaway disk coulter.

Chapter 3
EXPERIMENTAL PROCEDURE

3.1 Variables selected for study.

The effect of the following variables upon the depth-load relationship was studied:

1. Soil
   (a) Bulk density.
   (b) Surface condition.
2. Operation
   (a) Operational load.
   (b) Coulter size.

The following variables were kept constant (or assumed constant)

1. Soil moisture content.
2. Forward speed.
3. Soil type.

3.2 Equipment used.

3.2.1 Equipment used to measure force and depth.

1. Seed drill: A "Kirschmann" double disk seed drill with coulter attachments was used (figure 3.1). There were 20 units (seed openers) spaced evenly over a total width of 10 feet (figure 3.2). Five different sizes of coulters (9 1/2 in., 13 1/2 in., 14 1/2 in., 17 in. notched and 18 in.) were used in the field test (figure 3.3).
2. Pulling unit: International Harvester Company (I.H.C.) Farmall 756 tractor equipped with 6.0/20.0 front tires and 15.5/38.0 rear tires.

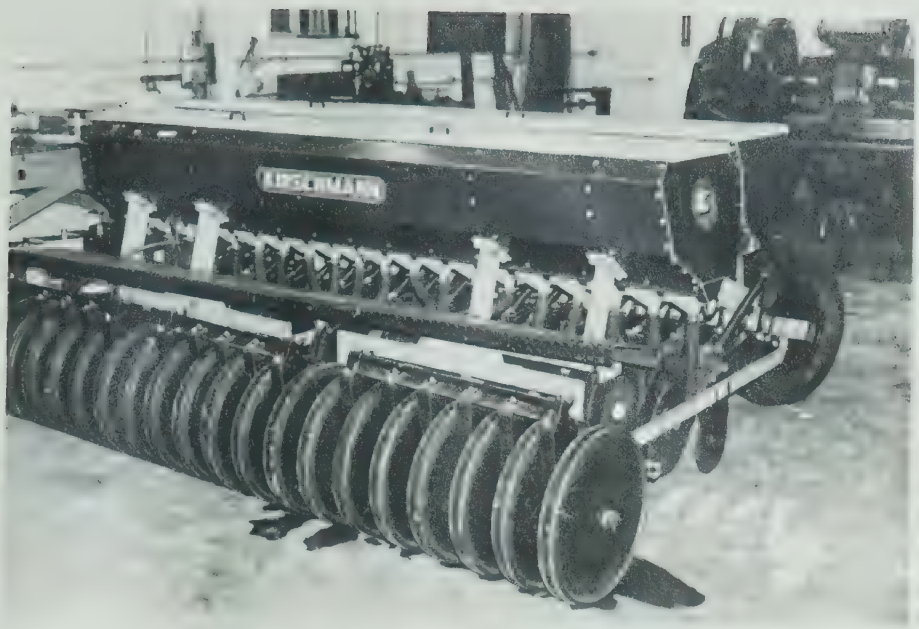


Figure 3.1: Experimental seed drill

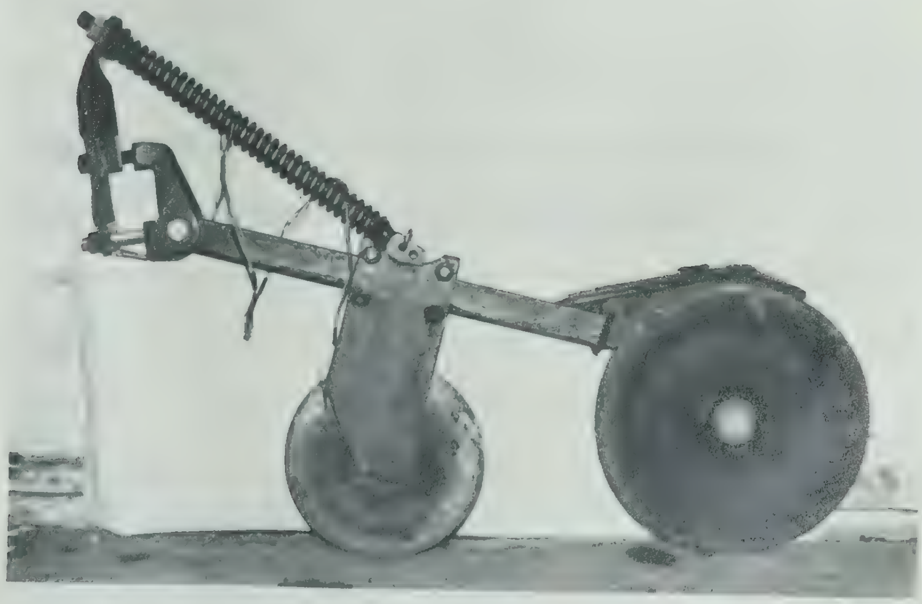


Figure 3.2: Unit of the seed drill including coulter and double disk furrow opener.

3. Force transducer: A four-strain-gauge circuit (Wheatstone bridge type with two gauges in tension and two gauges in compression) was used to sense the vertical load on the coulter/double disk (figure 3.4).
4. Recording equipment: A 6-channel ultra-violet recording system, type SE3006 was used to record force sensed by the transducer (figure 3.5). The recording system consisted of a paper supply and control-circuit balance, amplifiers, filters, galvanometers, and untra-violet recording unit. The recording paper (Kodak Linagraph Direct Print paper, 6 in. x 125 ft) was light sensitive and produced visible traces when exposed to ultra-violet light. Two ultra-violet recorders hereafter called U-V1 and U-V2 were used to record the voltage signals.
5. Tape measure: A 6 ft tape, readable to 0.125 in., was used to measure depth of coulter/double disk penetration.

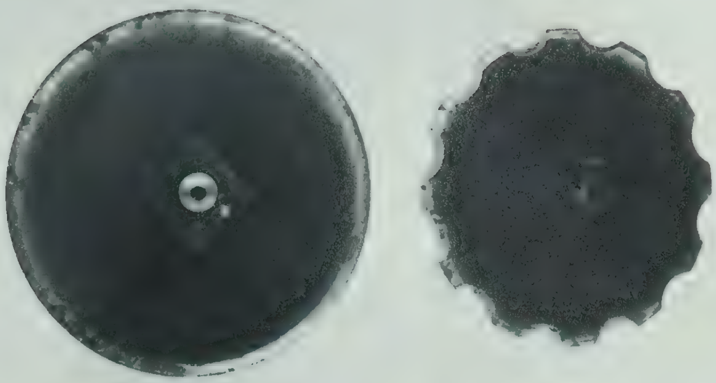
3.2.2 Equipment used to measure soil parameters.

1. Density/moisture surface gauge: Measures the in-place wet density and moisture content in lb/ft^3 of the soil utilizing a neutron source (4 mc. Radium-beryllium) which emits both gamma (for measuring density) and neutron (for measuring moisture content) radiation (figure 3.6). The gauge had the following specifications :

   Model: 5901 d/m

   Range

   Density channel: 60 - 160 lb/ft^3



a b

Figure 3.3: Two of the coulters used in the experiment; a. 18 inch plain coulter, b. 17 inch notched coulter.

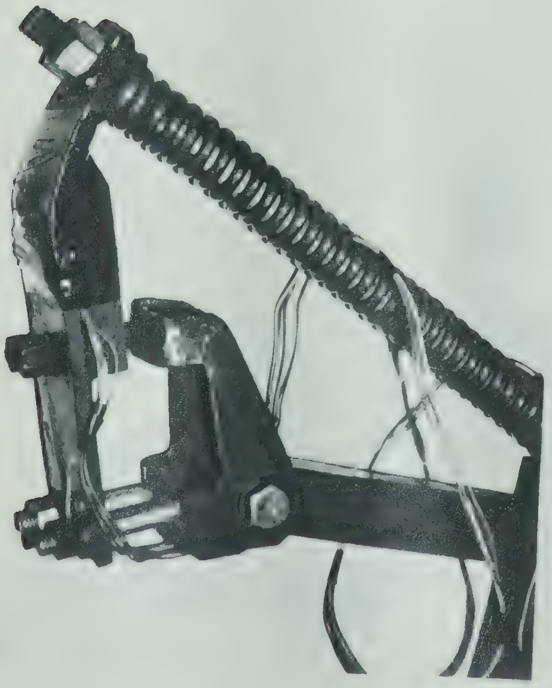


Figure 3.4: Force transducer on the unit.

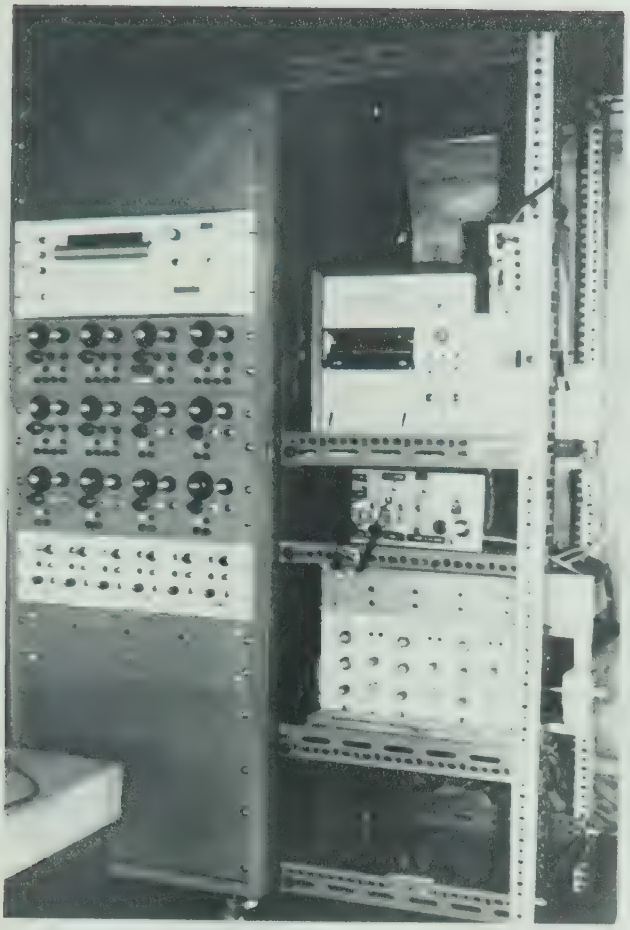


Figure 3.5: Recording equipment.

Figure 3.6: Density/moisture surface gauge and gauge scaler.

Moisture channel: 1 - 32 lb/ft^3

Operating voltage: 1300 - 1450 volts

Standard counts

Density: 4909$\pm$ 2%

Moisture: 3705$\pm$ 2%

Manufacturer: Nuclear Chicago

2. Gauge scaler: It is designed for use with the above Nuclear Chicago equipment and can be operated with an internal set of rechargable cadmium batteries, AC or DC supply. The scaler counts number of pulses for measuring density/moisture during a controlled time period (figure 3.6). The gauge scaler used had the following specifications:

   Model: 5920 d/m

   Operating voltage: 300 - 1500 volts

   Timer may be set for: 1/4, 1/2, 1 and 2 minutes.

   Counts capacity: 0 - 99, 999 counts

   Master switch: Five position power switch to select OFF, MOISTURE, DENSITY, TEST, or CHARGE circuits and power conditions as required.

3. Penetrometer: A proving ring penetrometer of the cone type (3) (ASAE Recommendation R313) was used to measure the penetration resistance of the test plot soil. The instrument consisted of a T-handle, one 18 in. penetration rod of 0.375 in. diameter marked every two inches, one proving ring of 250 lb capacity with dial indicator, and a removable 30° cone of 0.2 sq in. base area (figure 3.7). Manufacturer, Soiltest Inc., Illinois 60602 U.S.A.

4. Sheargraph: The Cohron sheargraph (6) is a torsional device to measure the soil shear strength (figure 3.8). The shear head covers a circular area of 2 sq in. The size of the shear head was chosen so that the operator can comfortably apply 15 psi normal stress to the sheared area. At 30 lb normal load, the axial deflection of the spring is two inches. A universal joint is located between the shear head and force sensing mechanism which allows a limited amount of free movement of the handle. The central shaft works through ball bushings in ball bearings so that both the axial and rotational motions are essentially friction-free. The forces from the handle are transmitted through the stainless steel spring to the recording drum and shear head.

   Model: D-250

   Manufacturer: Soiltest Inc., Illinois 60602 U.S.A.

5. Oxygen diffusion rate equipment: The oxygen diffusion rate (O.D.R.) was measured in the field by an apparatus utilizing platinum microelectrodes. The detailed description of the apparatus and theoretical considerations including some of the more recent information on the use of platinum microelectrodes system has been given by Letey et al (15), and Lemon and Erickson (14).

   Manufacturer: Dick's Machine and Tool, Lansing, Michigan.

6. Soil sampler: A one inch diameter steel cylinder with specially shaped and sharpened edge was used to extract soil samples to 12 in. depth to determine the moisture content.

Figure 3.8: Cohron sheargraph.

Figure 3.7: Proving ring penetrometer.

3.3 Calibration.

The load on the coulter/double disk unit was measured with the four-strain-gauge circuit (Wheatstone bridge type). The load from the hydraulic ram was applied to all the coulter units through a common square channel tool bar. The load applied by the tool bar changed the resistance of the strain gauge circuit. This change in resistance produced a proportional output voltage on the U-V recorder.

The calibration was carried out by placing a platform scale underneath the coulter or double disk which was attached to a selected unit (figure 3.9). Two platform scales were used for measuring the load on the coulter and doulbe disk individually when both the coulter and double disk were attached to the unit. Due precautions were taken to ensure that all the coulter units were at the same level viz: ground level. The signal to the U-V recorder was zeroed when no load was applied and the amplification adjusted to incorporate the maximum load under operating conditions. The load on the coulter units was applied from the hydraulic ram at successively increasing increments and the readings noted on both the U-V recorder and the platform scale.

3.4 Field test procedure.

Two experimental plots (fallow field and stubble field) of Malmo silty clay loam were used for the test purposes. The stubble field was approximately 300 ft x 40 ft and was used in its natural condition. The fallow field of approximately 250 ft x 60 ft was packed with two passes of the I.H.C. 756 tractor (gross weight 9800 lb) over the field. On one half of the plot, wheat straw was applied at a rate of 4000 lb/acre.

After the first set of tests on the plain and strawed fields, the field density was increased further by several passes of the tractor over the field before commencing the second series of tests. The tests on the stubble field were restricted to only one field density.

Each series of tests consisted of two sets of units (20 and 14) with and without an additional load of 1000 lb on the seed drill. Further, with every combination of load and units, coulter sizes of 9 1/2, 13 1/2, 14 1/2, 17 (notched) and 18 in. were used with and without the double disk and one run was made for each of the static and dynamic conditions. The testing scheme is diagramatically shown in figure 3.11.

3.4.1 Measurement of force and depth.

The following sequence was followed for measurements in a given run.

1. The generator and the tractor were checked for any malfunctioning.
2. The generator was started and the recording unit turned on at least 30 minutes prior to the commencement of the run.
3. The transducer was connected to the recording unit.
4. Load was applied by the hydraulic ram in increasing increments. For each setting of the hydraulic ram, the tractor was stopped intermittently and two to three depth measurements were made with the measuring tape (figure 3.10). The corresponding lines of deflection were recorded on the U-V recorder. The recording unit and the generator were carried in a van moving parallel to the tractor (figure 3.12).

Figure 3.9: Calibration of 17 inch notched coulter.

Figure 3.10: Depth measurement in the field.

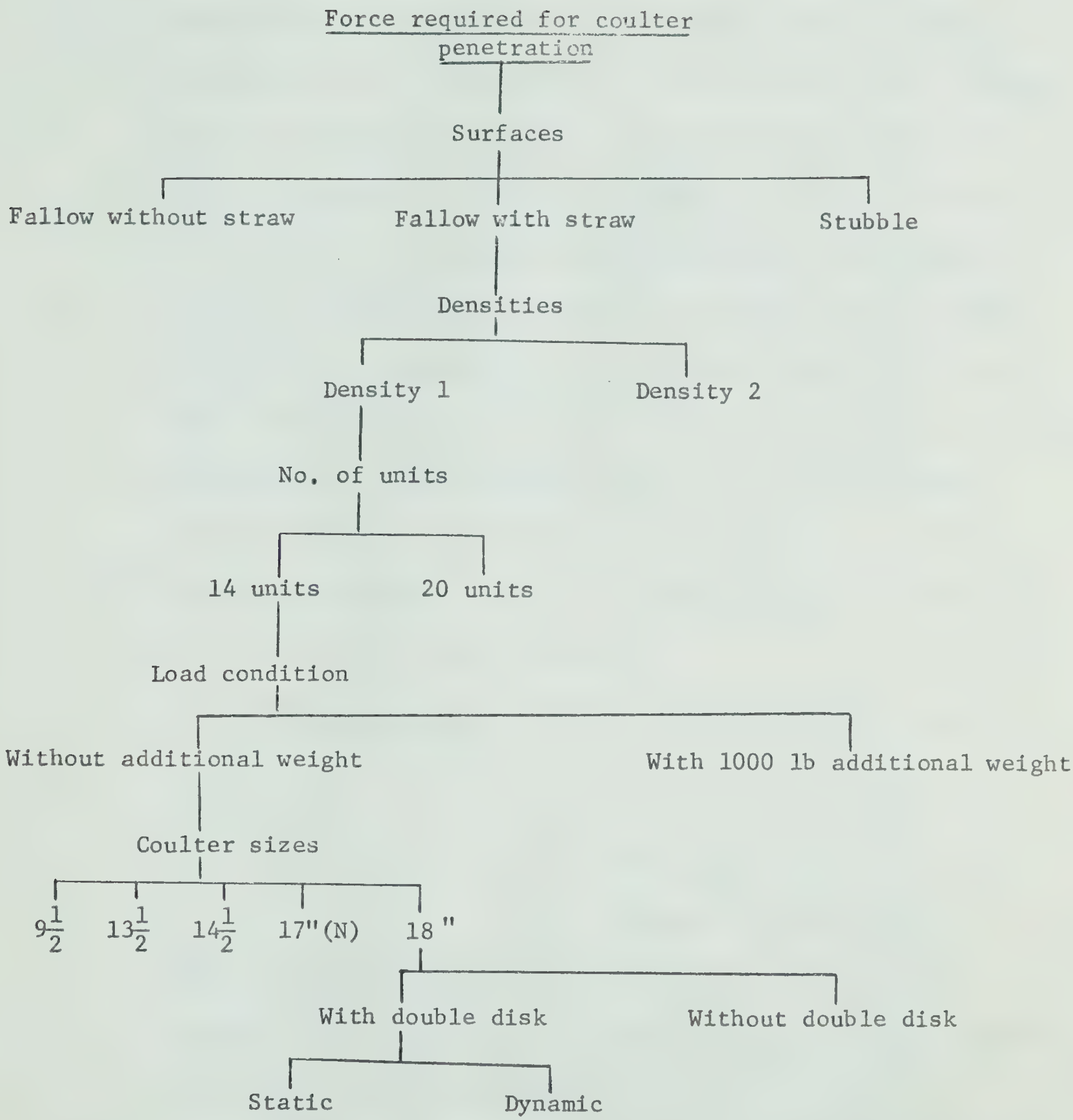


Figure 3.11: Outline of the testing scheme.

3.4.2 Soil parameter measurements.

1. Bulk density: The surface density moisture gauge was used to measure the bulk density of the test field. The equipment was calibrated (as per manufacturer's instructions) in the workshop prior to field use. The gauge scaler was used to count the number of pulses per minute. One square foot of the area of the soil surface was prepared by levelling and smoothing the surface. The gauge was placed on the surface firmly to ensure good contact. Subsequently, the knob was turned on to read counts for moisture and density measurements. The total numbers of counts over one minute were noted and the corresponding values of moisture and density were obtained from the d/m calibration graphs in lb/ft^3. Percentage moisture content was calculated by the following formula:

$$\%\ \text{moisture content} = \frac{\text{moisture content } (lb/ft^3)}{\text{dry density } (lb/ft^3)} \times 100$$

where

$$\text{dry density } (lb/ft^3) = \text{bulk (wet) density } (lb/ft^3) - \text{moisture content } (lb/ft^3)$$

The properties measured by this gauge are average values between ground level and 6 in. depth. Accuracy of the order of $\pm$ 1 lb/ft^3 has been reported (7).

2. Moisture content: Moisture content was also determined by the gravimetric method on a dry weight basis. A soil sampler was used to extract the soil to 12 in. depth (figure 3.13). For each test field, four random samples were taken over the field and subsequently oven dried in small cans. Moisture content was

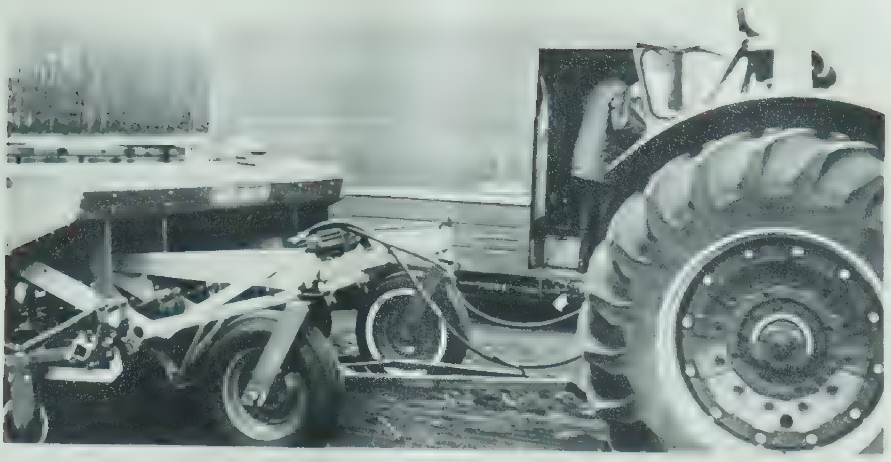


Figure 3.12: View of the pulling unit, test seed drill and van equipped with recording equipment.

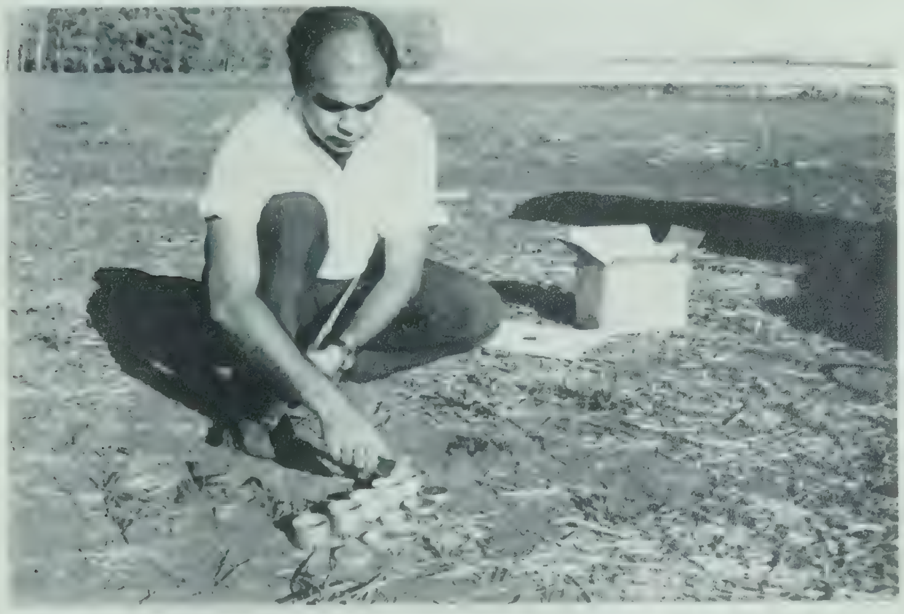


Figure 3.13: Soil samples for moisture content.

calculated by the following formula:

$$\% \text{ moisture content} = \frac{\text{Wt. of moist soil} - \text{Wt. of dry soil}}{\text{Wt. of dry soil}} \times 100$$

3. Shear strength: To measure the soil shear strength the Cohron sheargraph was used. The sheargraph was completely inserted into the soil, normal stress was applied to the shear surface through axial deflection of the spring, and shearing stress was applied by twisting the recording drum until the soil failed. After soil shear failure occured, normal load was gradually reduced. Since the soil sustains only a given amount of shearing stress for a particular normal load, the recording pen traced the curve of the shear stress vs. normal stress on the recording paper which was wrapped around the recording drum. The values of the strength parameters c and $\emptyset$ were found from the curve.

4. Oxygen diffusion rate: O.D.R. equipment was used to measure the oxygen diffusion rate. Potential was applied across a porous cup and the platinum electrodes (all in the soil). The cup formed the anode, through a potassium chloride bridge to a silver-silver chloride cell. Ten platinum electrodes (cathodes) were connected simultaneously. After equilibrium, each platinum electrode was switched in turn into the micro-ammeter circuit, and the current recorded, while the potential on the other nine remained undisturbed. 0.65 volts was applied, and five minutes allowed for stabilization. The electrodes were carefully inserted into the soil to minimize

alteration of the soil oxygen status at that point. Good contact between the porous cup and soil was ensured by proper compaction of the soil around the cup. The average of ten readings constituted one observation at any one location. To calculate the oxygen diffusion rate (gm/cm^2-min), the following formula was used.

$$\text{O.D.R.} = \frac{i}{A} \times 0.497 \times 10^{-8} \text{ gm/cm}^2\text{-min.}$$

where

i = current measured (microamp.)

A = surface area of the platinum (cm^2).

Surface area of the platinum electrodes was determined in 3% Bentonite solution. For details, see Appendix A.

5. Penetration resistance: To measure the penetration resistance, a proving ring penetrometer equipped with a 30^o cone was used. The penetrometer was pushed into the ground and dial readings (pounds) were taken at two inch intervals to 12 in. depth. The force readings were divided by the cone base area to obtain pressure in pounds per square inch.

Chapter 4

ANALYSIS AND RESULTS

There are generally three aspects to the investigation of a given physical phenomenon, namely the design of the experiments for information generation, the actual experimentation and finally the extraction of information in the data, that is, the analysis. An intelligent design of experiments ensures that the data contains useful information and thus the design problem is the more fundamental one. Nevertheless, correct and appropriate analysis is essential to the understanding of the phenomenon.

4.1 Calibration model.

For computer work, it is convenient to have a mathematical relation for converting the deflection readings on the U-V into load. Among the several models tested against the actual calibration data, the following linear model was found to be satisfactory.

$$L = b_1\delta + b_2\delta^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 4.1$$

where, L is load on the coulter/double disk and δ is the lines of deflection on the U-V paper. Tables 4.1 and 4.2 give the least square estimates for the parameters b_1 and b_2 along with the variance of fit σ^2 for the two U-V's employed in this work. For example, $\sigma^2 = 16.67$ for 9 1/2 in. coulter (using U-V1) implies that the 95% confidence limits of the load prediction based on the model (equation 4.1) will be approximately $\pm$ 2σ or $\pm$ 8.2 lb. In other words, using the calibration equation 4.1 with the parameters as given in table 4.1 would yield the correct load within $\pm$ 8 lb 95% of the time for a 9 1/2 in. coulter. This, of course, assumes that the field conditions with regard to the leveling

TABLE 4.1. CALIBRATION PARAMETERS FOR U-V 1.

Coulter Size (in.)	Parameters		Variance (σ^2)
	b_1	b_2	
9 1/2	2.707	0.0421	16.67
13 1/2	2.826	0.0737	94.56
14 1/2	3.447	0.0735	46.34
17 (N)*	3.818	0.0992	399.0
18	5.355	0.1085	157.2
Double disk 13 1/2	1.669	0.0090	9.14

TABLE 4.2. CALIBRATION PARAMETERS FOR U-V 2.

Coulter Size (in.)	Parameters		Variance (σ^2)
	b_1	b_2	
9 1/2	3.274	0.0307	18.78
13 1/2	4.102	0.0388	16.19
14 1/2	3.774	0.0599	33.24
17 (N)	7.837	0.1578	285.3
18	4.592	0.2669	458.4
Double disk 13 1/2	1.246	0.0115	5.3

* N - Notched coulter.

and positioning of the coulter are similar to those during the calibration procedure. The smoothed calibration curves generated by model 4.1 are given in figures 4.1 and 4.2 for both U-V1 and U-V2. An APL program LINM that computes the least square estimates of the parameters, the variance of fit $\hat{\sigma}^2$ and the 95% confidence limits of the parameters for the linear model is given in Appendix B.

4.2 Models and parameter estimation for the field data.

Having decided to use mathematical models to describe the relationship between depth of penetration and the applied load, the problem faced was finding suitable models for this purpose. Several models were investigated and the following model was selected as the most suitable in describing the true relationship.

$$d = \frac{b_1 L}{(1 + b_2 L)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 4.2$$

where d = depth of the coulter/double disk penetration in inches and L is the load applied to the coulter/double disk unit in pounds. As an example of the model discrimination process which is required in selecting an adequate model, the following two competing models were considered in addition to 4.2.

$$d = b_1 L + b_2 L^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 4.3$$

$$d = b_1 + b_2 \ln L \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 4.4$$

When the models 4.2, 4.3 and 4.4 were fitted to the field data for several coulter sizes and field conditions, model 4.2 gave consistently low variance of fit $\hat{\sigma}^2$ (and in most instances the lowest).

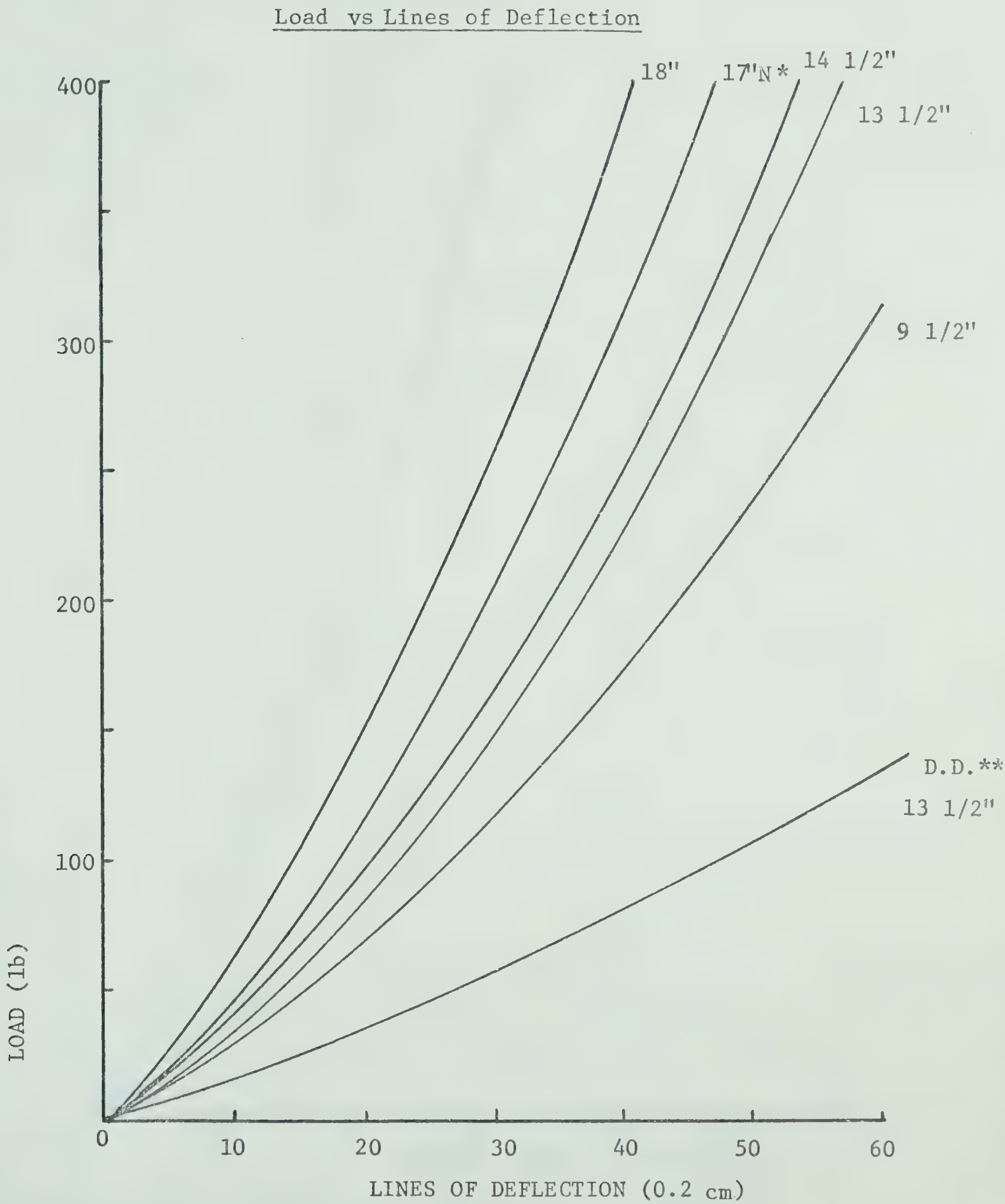


Figure 4.1: Calibration curves (U - V 1).

* Notched coulter.
** Double disk.

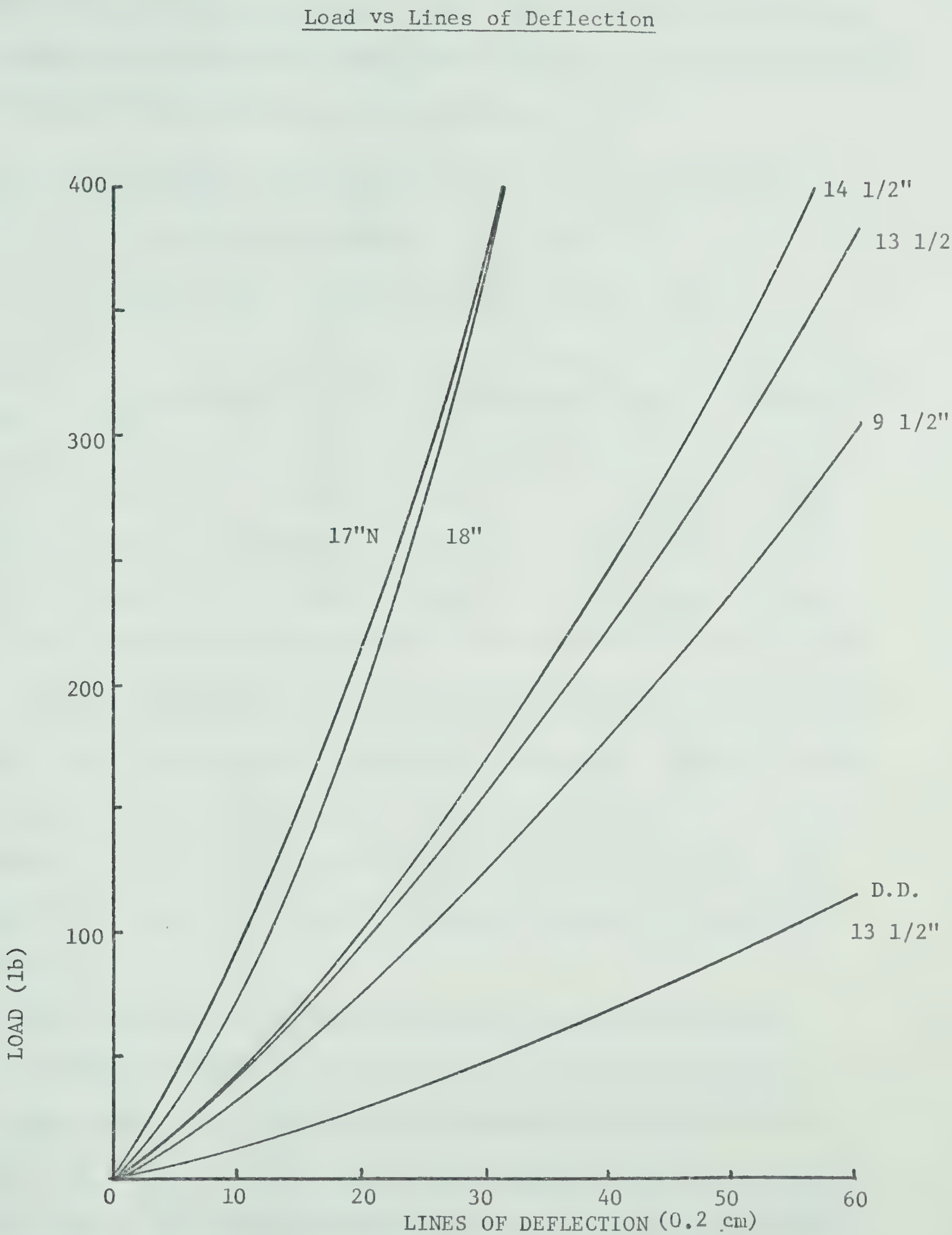


Figure 4.2: Calibration curves (U - V 2).

Model 4.4 was found to be the next best. Table 4.3 gives the results of regression analysis with these three models for the 9 1/2 in. coulter on the fallow field (density 1) using U-V1.

TABLE 4.3. PARAMETERS FOR FIELD DATA OF 9 1/2" COULTER IN DYNAMIC CONDITIONS USING MODELS 4.2, 4.3 and 4.4.
Fallow field - Density 1, without straw, (U-V1)

Model	Parameters b_1	Parameters b_2	95% Confidence Limit $\pm b_1$	95% Confidence Limit $\pm b_2$	Variance σ^2
4.2	0.05416	0.01437	0.0153	0.00631	0.1499
4.3	0.03216	-0.0000941	0.0046	0.0000287	0.1915
4.4	-1.338	0.7707	0.5319	0.1227	0.1528

An APL program MGT employing Marquardt's (18) algorithm for a non-linear model was employed in this work. The program computes the least square estimates of the parameters, the variance of fit and the 95% confidence limits of the parameters for the non-linear model. The program MGT along with the other supporting programs are given in Appendix B.

The first step in the model fitting (or regression analysis) process was obtaining the average deflection produced on the U-V recording paper. This was achieved by measuring the area under the trace with a planimeter and dividing the measured area by the length of the trace. The average deflection (δ) thus measured was converted into load (L) using the calibration model 4.1 and appropriate

calibration parameters from table 4.1 and 4.2. This was followed by parameter estimation using the programs LINM or MGT. This procedure was repeated for every coulter size and field condition.

Although separate field runs were carried out under different load conditions (e.g. extra load or reducing the number of units, etc.), the data still followed the relation 4.2. All that was really achieved by placing the additional load or decreasing the number of units was to generate some data in the high load region. In other words, all the data for a given coulter size and field condition followed a single curve and thus gave nearly the same estimates for b_1 and b_2 in the model 4.2. Table 4.4 gives the parameter estimates and their 95% confidence limits for four different load conditions on the 9 1/2 in. coulter. The field data for the same coulter and for all the four load conditions are shown in figure 4.3 as an illustration. Consequently, all the field runs for a given coulter size and field condition were analyzed jointly and only one set of parameter estimates was obtained.

The parameter estimates along with their 95% confidence limits and the variance of fit for each combination of the coulter size and field condition are given in tables 4.5, 4.6, 4.7, 4.8 and 4.9.

4.3 Results and Discussion

4.3.1 Load Conditions

As discussed in the preceding section the different load conditions gave approximately the same estimate of parameters and did not alter the depth-load relationship. However, the different load conditions influenced the maximum load that could be applied on the coulter unit. Table 4.10 gives the maximum load that could be applied under various load conditions for each of five coulters and the double disk. The maximum depth that was achieved

TABLE 4.4. PARAMETERS FOR 9 1/2 IN. COULTER FOR DIFFERENT LOAD CONDITIONS. FALLOW FIELD - DENSITY 1, WITHOUT STRAW. (U - V 1).

Load Conditions	Parameters		95% Confidence Limits	
	b_1	b_2	$\pm b_1$	$\pm b_2$
No load, 20 units	0.03833	0.007167	0.01084	0.004363
1000 lb load, 20 units	0.02498	0.004508	0.01528	0.006823
No load, 14 units	0.08766	0.02766	0.02752	0.01077
1000 lb load, 14 units	0.0785	0.02227	0.03036	0.01141

Load vs. Depth

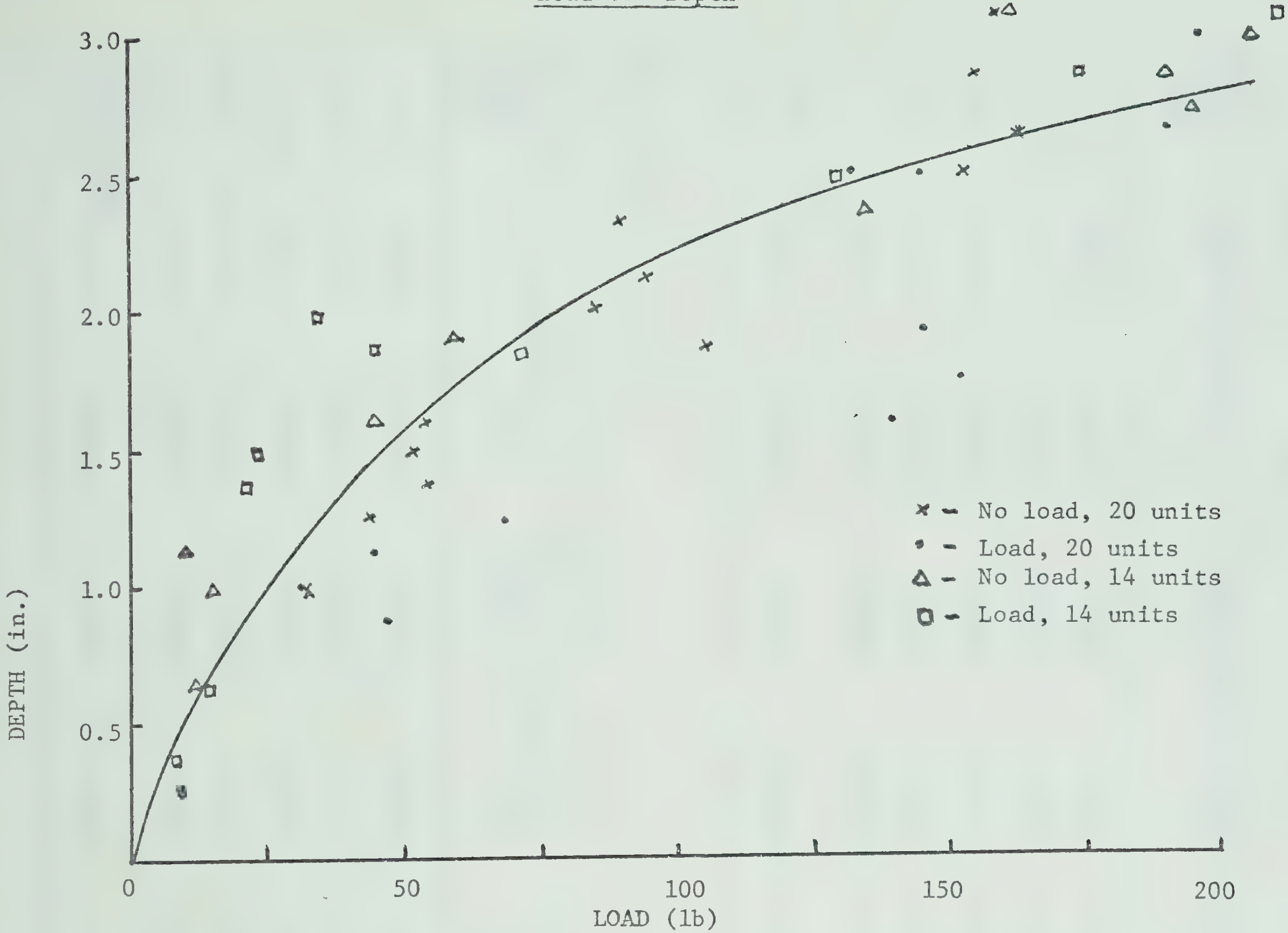


Figure 4.3: Depth/load curve for all the four load conditions on fallow field, density 1, without straw.

TABLE 4.5. PARAMETERS FOR FIELD DATA. FALLOW FIELD - DENSITY 1, WITHOUT STRAW. (U - V 1)

(a) Static

Coulter Size (in.)	Parameters b_1	b_2	95% Confidence Limit $\pm b_1$	$\pm b_2$	Variance σ^2
9 1/2	0.05803	0.02418	0.01901	0.0113	0.2007
13 1/2	0.1440	0.0677	0.06228	0.03614	0.260
14 1/2	0.04227	0.01465	0.00806	0.00476	0.0541
17N	0.07665	0.01988	0.0201	0.0080	0.1337
18	0.1021	0.03477	0.0295	0.01215	0.1404
double disk 13 1/2	0.02785	0.01126	0.01108	0.00899	0.07626

(b) Dynamic

Coulter Size (in.)	Parameters b_1	b_2	95% Confidence Limit $\pm b_1$	$\pm b_2$	Variance σ^2
9 1/2	0.05416	0.01437	0.0153	0.00631	0.1499
13 1/2	0.09170	0.03134	0.03662	0.0170	0.2237
14 1/2	0.1275	0.04528	0.049	0.0225	0.2304
17N	0.1208	0.03645	0.06056	0.0233	0.3053
18	0.07421	0.02079	0.06111	0.02054	0.4171
double disk 13 1/2	0.04121	0.01086	0.01397	0.0076	0.1043

TABLE 4.6. PARAMETERS FOR FIELD DATA. FALLOW FIELD - DENSITY 1, WITH STRAW. (U - V 1)

(a) Static

Coulter Size (in.)	Parameters		95% Confidence Limit		Variance
	b_1	b_2	$\pm b_1$	$\pm b_2$	σ^2
9 1/2	0.01843	0.01058	0.0133	0.0131	0.2260
13 1/2	0.02633	0.02493	0.01146	0.0155	0.03290
14 1/2	0.04374	0.03243	0.02323	0.02239	0.08103
17N	0.08256	0.04666	0.04144	0.02839	0.1575
18	0.05951	0.04185	0.08939	0.07104	0.2403
double disk 13 1/2	0.01036	0.00485	0.00974	0.0140	0.07509

(b) Dynamic

Coulter Size (in.)	Parameters		95% Confidence Limit		Variance
	b_1	b_2	$\pm b_1$	$\pm b_2$	σ^2
9 1/2	0.02077	0.00602	0.00826	0.004979	0.1461
13 1/2	0.04160	0.01866	0.02244	0.01585	0.1874
14 1/2	0.03627	0.01405	0.01408	0.008485	0.1446
17N	0.06016	0.02189	0.02493	0.01201	0.1848
18	0.02841	0.00753	0.01654	0.007038	0.3699
double disk 13 1/2	0.02566	0.01089	0.01702	0.01438	0.1085

TABLE 4.7. PARAMETERS FOR FIELD DATA. STUBBLE FIELD. (U - V 1).

(a) Static

Coulter Size (in.)	Parameters		95% Confidence Limit		Variance
	b_1	b_2	$\pm b_1$	$\pm b_2$	σ^2
9 1/2	0.02094	0.00527	0.01137	0.007212	0.2650
13 1/2	0.02910	0.00821	0.01152	0.007667	0.1494
14 1/2	0.05083	0.01529	0.0176	0.0102	0.1734
17N	0.1493	0.04791	0.05389	0.02397	0.1935
18	0.05367	0.01489	0.02329	0.009379	0.2699
double disk 13 1/2	0.008516	0.006554	0.009219	0.01819	0.03667

(b) Dynamic

Coulter Size (in.)	Parameters		95% Confidence Limit		Variance
	b_1	b_2	$\pm b_1$	$\pm b_2$	σ^2
9 1/2	0.03095	0.00607	0.00811	0.00371	0.1702
13 1/2	0.05968	0.02065	0.01776	0.00907	0.1375
14 1/2	0.04379	0.01017	0.009617	0.004508	0.1332
17N	0.08007	0.02096	0.02138	0.008562	0.1515
18	0.04053	0.00806	0.01105	0.00373	0.3022
double disk 13 1/2	0.03041	0.00444	0.01009	0.00502	0.1164

TABLE 4.8. PARAMETERS OF FIELD DATA. FALLOW FIELD - DENSITY 2, WITHOUT STRAW. (U - V 2)

(a) Static

Coulter Size (in)	Parameters b_1	Parameters b_2	95% Confidence Limit $\pm b_1$	95% Confidence Limit $\pm b_2$	Variance σ^2
9 1/2	0.01330	0.003519	0.003101	0.002162	0.02385
13 1/2	0.04266	0.02297	0.02624	0.02093	0.1320
14 1/2	0.02700	0.01050	0.009305	0.006169	0.08240
17N	0.06762	0.03118	0.04341	0.02521	0.1225
18	0.02942	0.01120	0.01699	0.008189	0.2742
double disk 13 1/2	0.01093	0.1470	0.01877	0.04463	0.04974

(b) Dynamic

Coulter Size (in)	Parameters b_1	Parameters b_2	95% Confidence Limit $\pm b_1$	95% Confidence Limit $\pm b_2$	Variance σ^2
9 1/2	0.01623	0.004622	0.003199	0.001997	0.04067
13 1/2	0.02506	0.007927	0.004801	0.002992	0.05379
14 1/2	0.03082	0.01276	0.00803	0.005015	0.08972
17N	0.03134	0.01300	0.01167	0.006019	0.07169
18	0.01390	0.004166	0.004376	0.001841	0.1077
double disk 13 1/2	0.01259	0.000785	0.003352	0.003015	0.02406

TABLE 4.9. PARAMETERS FOR FIELD DATA. FALLOW FIELD - DENSITY 2, WITH STRAW.(U - V 2)

(a) Static

Coulter Size (in)	Parameters b_1	Parameters b_2	95% Confidence Limit $\pm b_1$	95% Confidence Limit $\pm b_2$	Variance σ^2
9 1/2	0.00467	-0.000415	0.002783	0.003079	0.1064
13 1/2	0.004733	-0.001382	0.00258	0.002358	0.06814
14 1/2	0.01148	0.01131	0.008739	0.01408	0.03455
17N	0.1337	0.08799	0.5824	0.4082	0.1821
18	0.05822	0.02608	0.06306	0.03328	0.2345
double disk 13 1/2	0.01210	0.04745	0.01521	0.07421	0.00301

(b) Dynamic

Coulter Size (in)	Parameters b_1	Parameters b_2	95% Confidence Limit $\pm b_1$	95% Confidence Limit $\pm b_2$	Variance σ^2
9 1/2	0.004354	0.001266	0.001293	0.001017	0.08681
13 1/2	0.01081	0.002358	0.004196	0.003407	0.08743
14 1/2	0.01310	0.003439	0.002937	0.002095	0.05629
17N	0.04046	0.01935	0.04439	0.0239	0.1035
18	0.01352	0.004814	0.009008	0.004397	0.1501
double disk 13 1/2	0.01016	0.001449	0.01081	0.01296	0.1360

TABLE 4.10. MAXIMUM LOAD THAT COULD BE APPLIED AND DEPTH ACHIEVED UNDER VARIOUS LOAD CONDITIONS IN THE STUBBLE FIELD.

Coulter Size (in.)	Load Conditions	Maximum Load That Can Be Applied (lb)	Predicted Depth (in.)
9 1/2	No load, 20 units	120	2.15
13 1/2	No load, 20 units	115	2.03
14 1/2	No load, 20 units	120	2.37
17N	No load, 20 units	190	3.04
18	No load, 20 units	150	2.72
double disk 13 1/2	No load, 20 units	97	2.07
9 1/2	1000 lb load, 20 units	150	2.4
13 1/2	1000 lb load, 20 units	140	2.15
14 1/2	1000 lb load, 20 units	180	2.79
17N	1000 lb load, 20 units	235	3.15
18	1000 lb load, 20 units	260	3.3
double disk 13 1/2	1000 lb load, 20 units	105	2.2
9 1/2	No load, 14 units	175	2.62
13 1/2	No load, 14 units	180	2.32
14 1/2	No load, 14 units	105	2.25
17N	No load, 14 units	140	2.85
18	No load, 14 units	260	3.3
double disk 13 1/2	No load, 14 units	113	2.3
9 1/2	1000 lb load, 14 units	200	2.8
13 1/2	1000 lb load, 14 units	195	2.37
14 1/2	1000 lb load, 14 units	190	2.85
17N	1000 lb load, 14 units	310	*3.5
18	1000 lb load, 14 units	385	*4.1
double disk 13 1/2	1000 lb load, 14 units	113	2.3

* Actual depths obtained in the field.

is also tabulated.

It can be seen that some additional depth of penetration can be achieved by placing extra load and/or by reducing the number of units. The unfavourable factors in the former case could be an increase in power consumption and in the latter case a decrease in the capacity of the seed drill.

4.3.2 Static, versus dynamic experiments.

The depth/load relationship for static conditions was found to be similar to that observed in the dynamic case except that the curve for the static condition lies below that of the dynamic condition. The difference is more marked for smaller coulters and the double disk and increases as the load increases. The parameter estimates have already been given in tables 4.5 to 4.9. Figure 4.4 compares the results of the 9 1/2 in. coulter for static and dynamic conditions.

4.3.3 Coulter size and type.

Figures 4.5, 4.6 and 4.7 give the plots of depth versus load for the various coulters and three different field conditions. The following observations are noteworthy.

1. For smaller loads, the medium sized coulters (13 1/2 and 14 1/2 in.) gave greater depth than the other coulters (except the notched 17 in. coulter).
2. When larger loads were applied, large size coulters (17 in. and 18 in.) gave greater depths than the other coulters.
3. The notched 17 in. coulter had a distinctly superior performance and gave greater depth than the other coulters except at very high loads where the 18 in. coulter was superior.

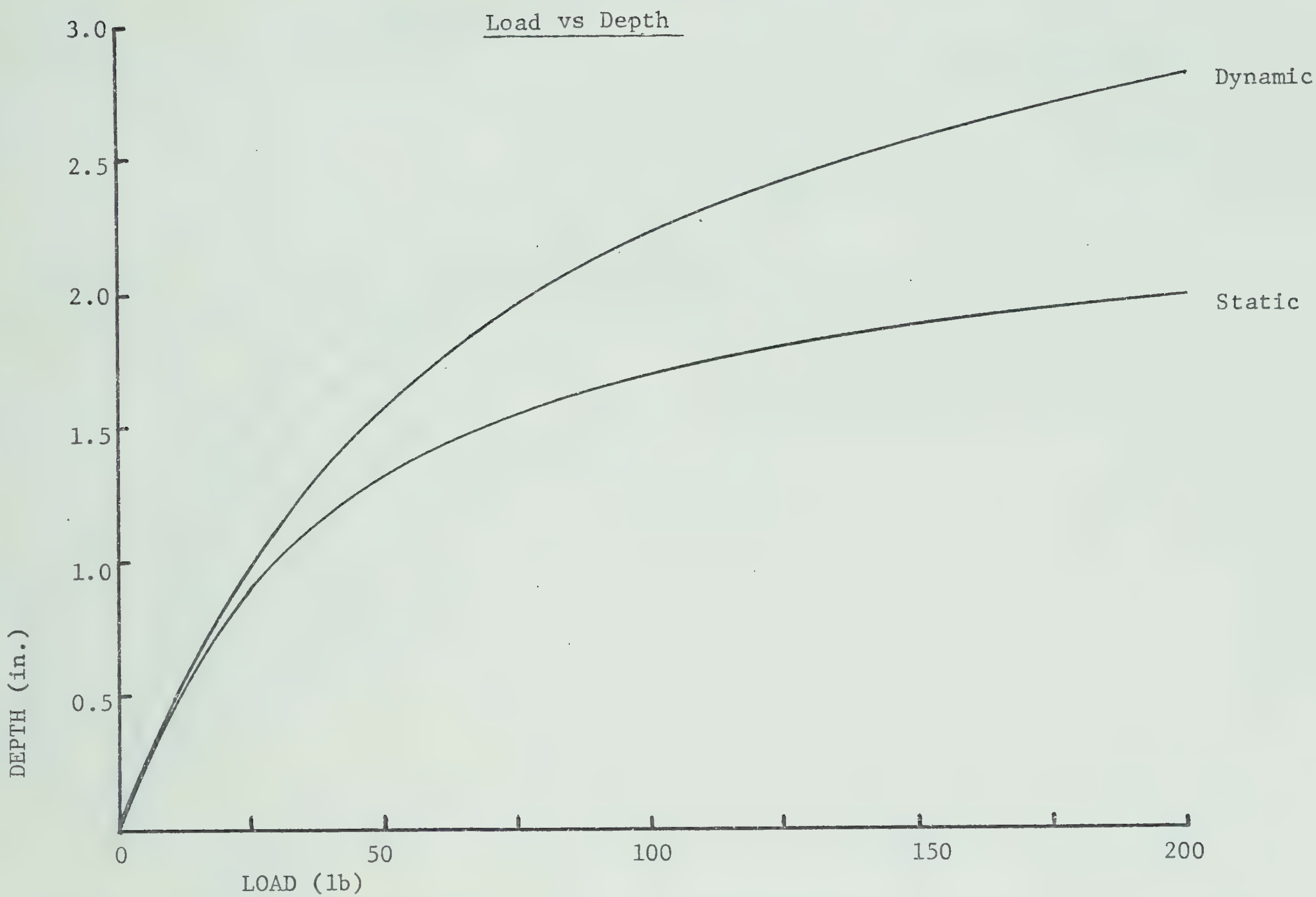


Figure 4.4: Depth/load curves in static and dynamic conditions for 9 1/2 in. coulter on fallow field, density 1, without straw.

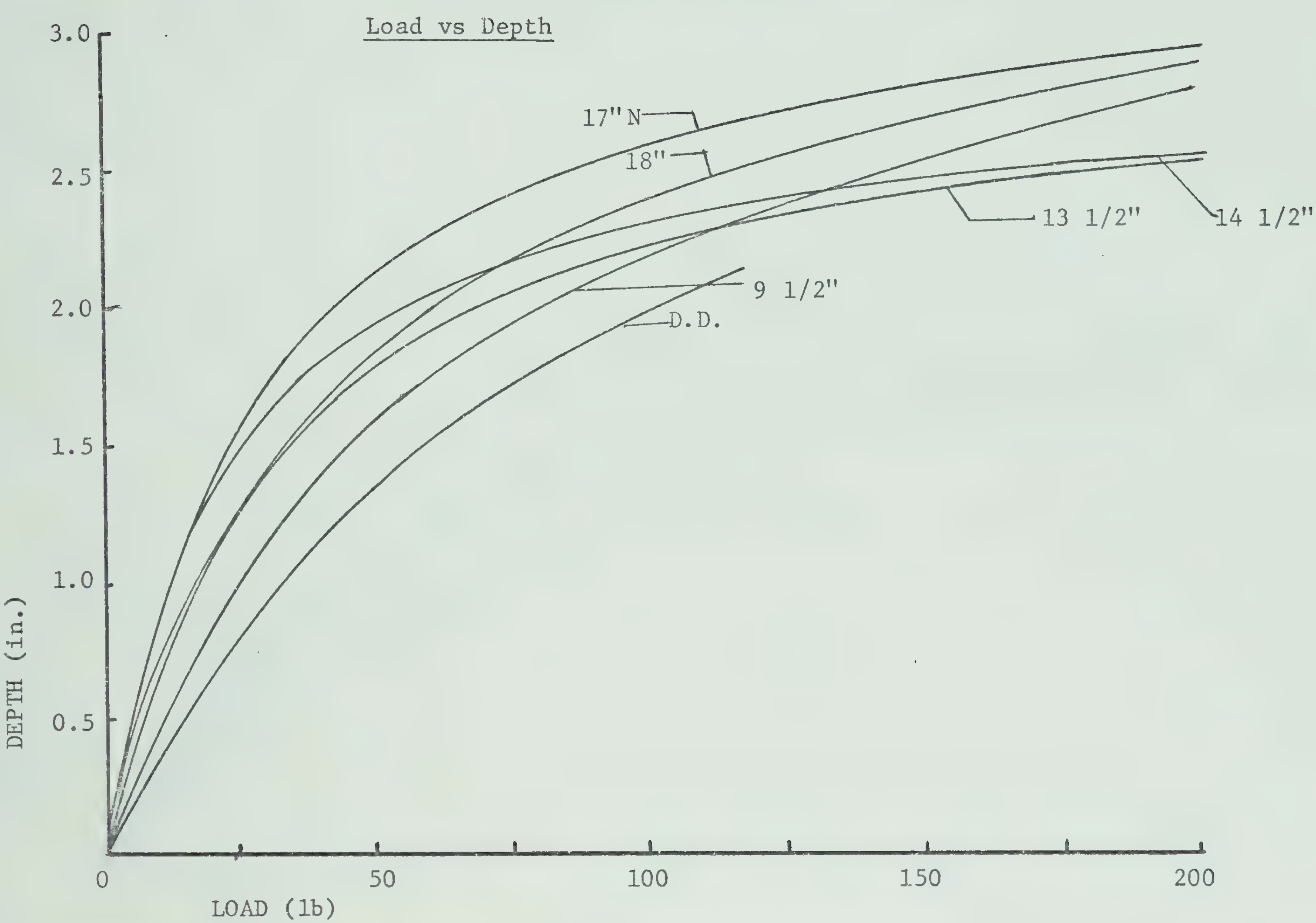


Figure 4.5: Depth/load curves for all the coulters and double disk on fallow field, density 1, without straw.

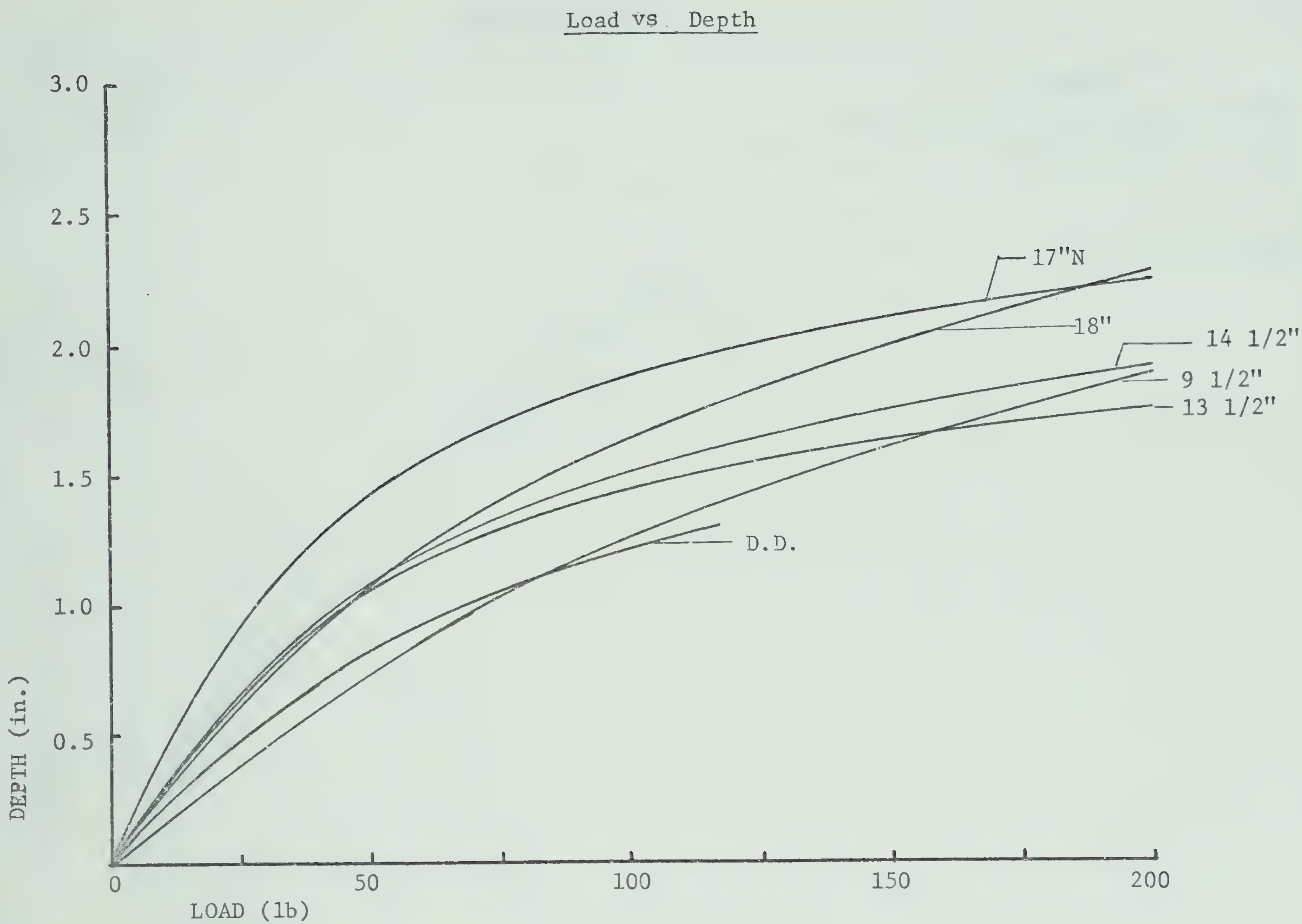


Figure 4.6: Depth/load curves for all the coulters and double disk on fallow field, density 1, with straw.

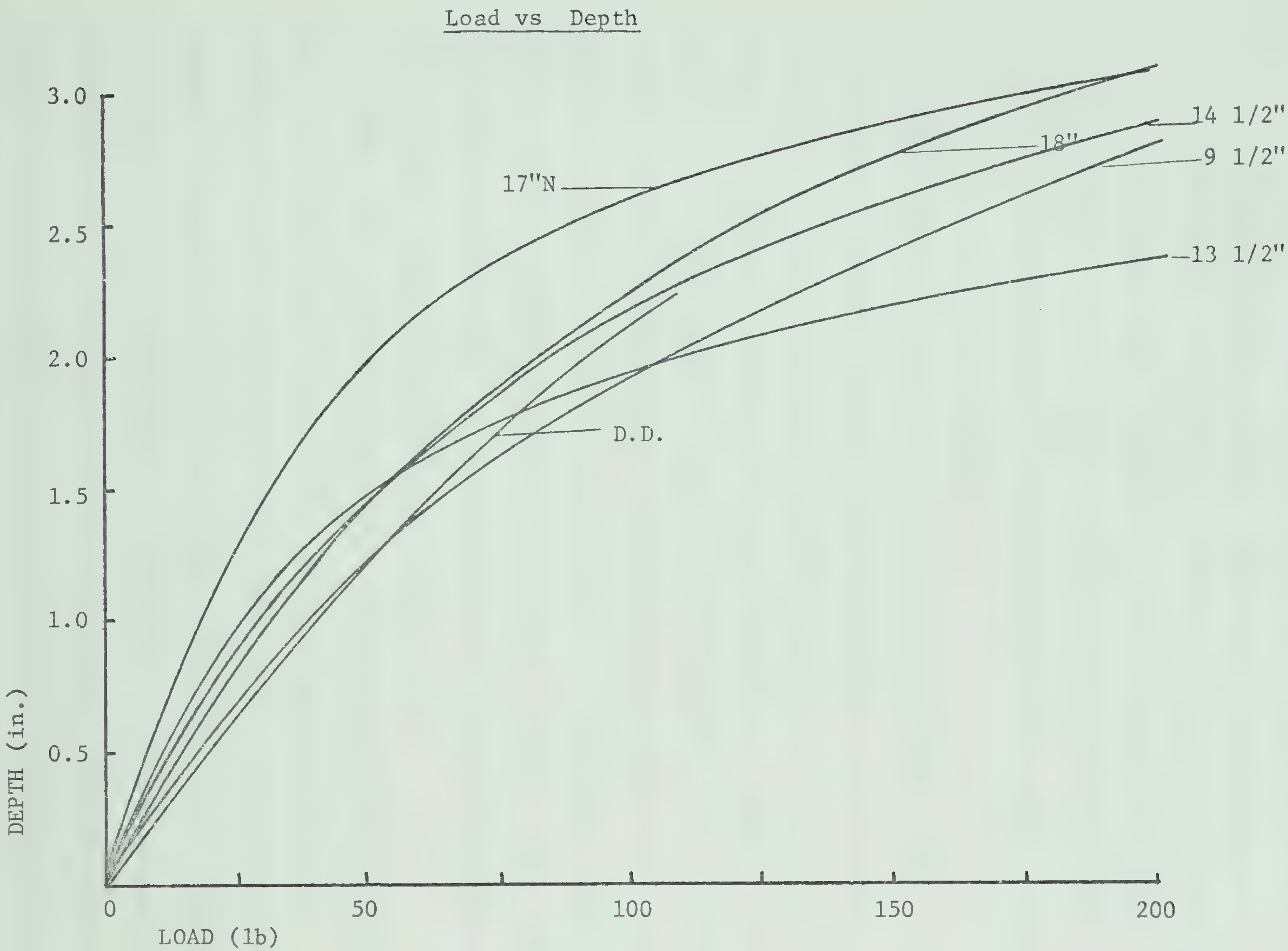


Figure 4.7: Depth/load curves for all the coulters and double disk on stubble field.

The performance of the 17 in. notched coulter was much better than the other coulters in the stubble and strawed field.

4. The double disk alone penetrated to a depth of two inches in fallow field (density 1, without straw) and stubble field. In the straw field the maximum penetration was 1.25 in.

5. In the straw field the penetration of the coulters varied directly as the diameter.

These observations are obtained only from the depth-load relationship. Another relevant observation made during the field experiments was that the distance between the double disk and the coulter should not be large otherwise the double disk may not follow in the groove made by the coulter. Larger coulters complicate this problem, however, smaller coulters have a definite disadvantage on the strawed fields in that the straw tends to accumulate in the front of the coulter. Another factor against the use of smaller sized coulters is the reduction in the maximum load that can be applied with a consequent reduction in the obtainable depth as discussed in section 4.3.1.

Thus, the selection of the most suitable coulter would depend upon the field conditions. Since the fields under minimum-tillage are invariably stubble and usually covered with straw, a notched coulter has definite advantages over the other type of coulters. It is difficult to determine the most suitable size of the coulter from the present study alone since only one notched coulter was employed. However, since some signs of the disk opener not following the coulter were observed in the field experiments, a somewhat smaller notched coulter perhaps of size

14 - 15 in.should be satisfactory.

4.3.4 Field conditions.

The depth of penetration is very significantly affected by the field conditions. The present study has confirmed the expected effect that the strawed and stubbled fields would give substantially lower depths of penetration than the fallow field (without straw). Figures 4.8 and 4.9 give the plots of depth versus load for 9 1/2 in.and 17 in. coulters respectively. These were generated by relation 4.2 and the best values of parameters from tables 4.5 to 4.9.

One interesting observation is regarding the effect of straw on depth achievement with the notched and plain coulter. It can be seen that there is a substantial downward drop in the load-depth curve for the 9 1/2 in.coulter for both the densities due to the effect of the straw. On the other hand, there is no apparent decrease in the depth for the 17 in.notched coulter over the strawed compacted field (density 2). This indicates that the resistance due to straw on compacted fields can be very easily overcome by large notched coulters. Similar conclusions for the performance of the notched coulter on the stubble field can also be drawn.

4.3.5 Coulter followed by the double disk.

So far only the depth/load characteristics of the single coulter or double disk has been discussed. The typical field application, however, would involve a double disk following a coulter of suitable size. Theoretically it is quite simple to obtain the depth-load relationship of the combined system from the characteristics of the individual components.

Equation 4.2 can be used to describe the depth/load relationship

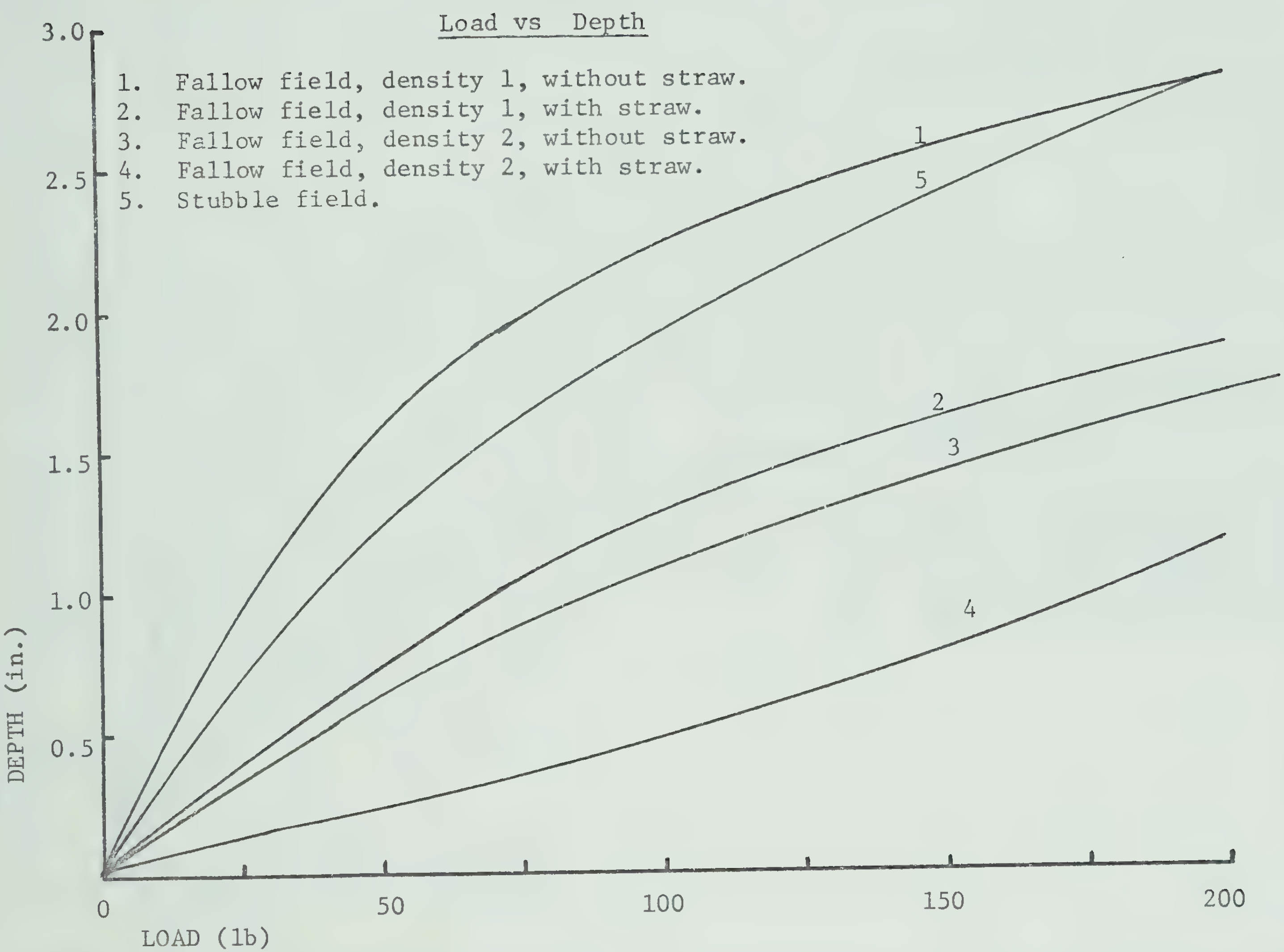


Figure 4.8: Depth/load curves for 9 1/2 in. coulter on all the five field conditions.

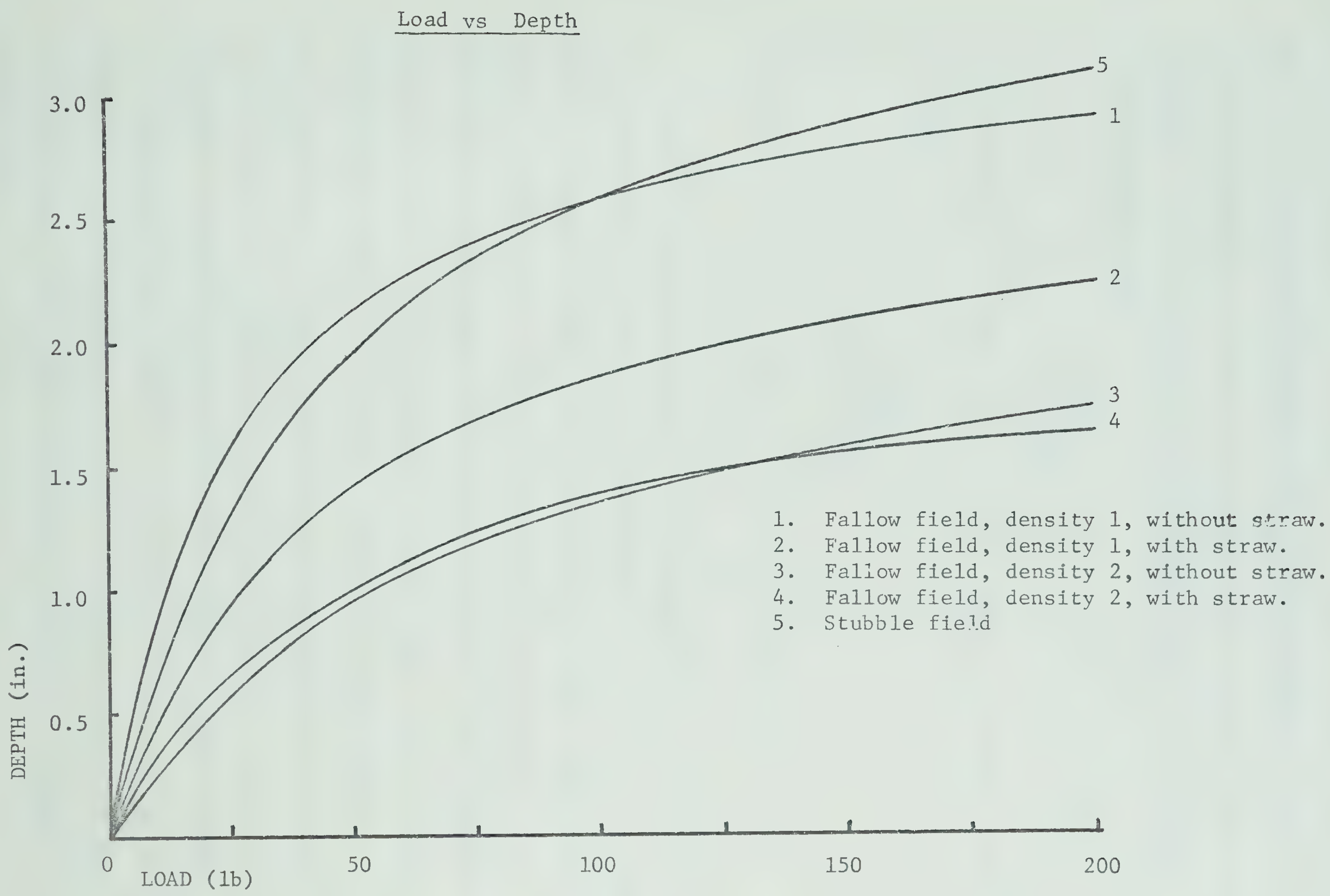


Figure 4.9: Depth/load curves for 17 in. notched coulter on all the five field conditions.

Let a_1, a_2 be the two parameters in 4.2 of the leading coulter and b_1, b_2 the corresponding parameters for the double disk for a given field condition. Then, the depth of the leading coulter dc carrying a load L_c may be written as:

$$dc = \frac{a_1 L_c}{1 + a_2 L_c} \qquad \text{. . . . . 4.5}$$

and the additional depth due to the double disk dd carrying a load L_d is simply

$$dd = \frac{b_1 L_d}{1 + b_2 L_d} \qquad \text{. . . . . .4.6}$$

Consequently, the total depth of the double disk shall be

$$d = dc + dd. \qquad \text{. .4.7.}$$

The above analysis, however, has assumed that L_c and L_d are known or can be obtained and that the double disk is following the coulter along its deepest groove. In actual practice neither may be true. Whereas the small mis-alignment of the double disk and the coulter may be accounted for by some sort of efficiency factor (less than one), there is no short cut to obtaining L_c and L_d other than the actual measurement. The problem, however, faced in the measurements of L_c and L_d is that with the rigid calibration scales placed under coulter and double disk in the laboratory experiments, measured L_c and L_d would not represent the field values for any given position of the hydraulic ram.

A somewhat better approach would be to measure the maximum depth obtainable in the field for the various field conditions with and without coulter. Such observations were made and are presented in table 4.11.

TABLE 4.11. MAXIMUM DEPTH ACHIEVED BY DOUBLE DISK WITH AND WITHOUT COULTERS FOR DIFFERENT FIELD CONDITIONS.

Coulter Size (in.)	Field Conditions	Max. depth achieved with coulters (in.)	Max. depth achieved without coulter (in.)
9 1/2	Fallow field	2.53	
13 1/2	density 1	2.44	
14 1/2	without straw	2.53	2.28
17 N		2.81	
18		2.62	
9 1/2	Fallow field	1.59	
13 1/2	density 1	1.47	
14 1/2	with straw	1.87	1.28
17 N		2.00	
18		1.84	
9 1/2	Stubble field	2.22	
13 1/2		2.28	
14 1/2		2.42	2.22
17 N		2.56	
18		2.56	
9 1/2	Fallow field	1.53	
13 1/2	density 2	1.69	
14 1/2	without straw	1.62	1.37
17 N		1.87	
18		1.78	
9 1/2	Fallow field	1.12	
13 1/2	density 2	1.22	
14 1/2	with straw	1.22	1.00
17 N		1.56	
18		1.44	

These depth readings are the mean of the maximum depth achieved for the four load conditions. As shown in table 4.11 using a coulter in front of the double disk increased the depth as compared to no coulter. Greater seeding depths were achieved with 17 in. notched coulter combination as compared to any other coulter, particularly in strawed fields. This increased depth varied from 14.4% (in stubbled field) to 56% (in both the strawed fields).

4.3.6 Measurements of the soil properties.

1. Bulk density: Four bulk density and moisture measurements were made for each test day using the density/moisture surface gauge as described in section 3.2.2. Table 4.12 gives the mean bulk (wet) density, mean dry density, 95% confidence limits and the variances of the measurements for the three test fields. The stubble field showed the lowest density whereas the fallow field (density 2), as expected gave the highest readings.

TABLE 4.12. MEAN BULK AND DRY DENSITIES, 95% CONFIDENCE LIMITS, AND VARIANCE OF THE FIELD CONDITIONS.

Field Conditions	Mean Density (lb/ft^3)		95% Confidence Limits	Variance σ^2
fallow field (density 1)	bulk density	66.7	±7.43	13.8
	dry density	49.0	±5.91	8.73
fallow field (density 2)	bulk density	74.5	±7.28	13.2
	dry density	58.1	±6.70	11.2
stubble field	bulk density	57.2	±4.04	4.08
	dry density	47.9	± .993	0.247

2. Penetrometer resistance: The penetrometer employed for this work (see section 3.2.2) was a very sensitive instrument. However, the inevitable consequences of high sensitivity rendered the measurements prone to incorrect reading due to low stability of the instrument. Consequently, a large number of measurements were taken to obtain adequate accuracy (as shown by the 95% limits and the variances). Mean penetration resistance in pounds for the cone of 0.2 sq in. base area, 95% confidence limits and variances are given in table 4.13 at depths of 2 in. to 12 in. and for all the three test fields. The results are plotted in figure 4.10.

   As is evident from a cursory comparison of table 4.12 and 4.13 the field density alone does not determine the compactness of the field. For example, the stubble field while having the lowest density gave maximum resistance to penetration. The other relevent factor influencing the resistance to penetration appears to be the moisture content. As will be seen in the next section the stubble field had the lowest moisture content and consequently this explains the high penetration resistance.

3. Moisture content: The results for moisture contents at depths of 2 to 12 in. obtained by gravimetric method for the three test fields are given in table 4.14 and are shown graphically in figure 4.11. Several readings at every 2 in. depth level for all the three test fields were taken on different days. The narrow confidence limits of the moisture contents in table 4.14 imply that moisture content essentially remained constant over the entire test period.

TABLE 4.13. MEAN PENETRATION RESISTANCE, 95% CONFIDENCE LIMITS, AND VARIANCE OF THE FIELD CONDITIONS.

Field Condition	Depth (in.)	Penetration Resistance (lb)	95% Confidence Limits	Variance σ^2
Fallow field (density 1)	2	12.8	± 4.71	5.56
	4	13.2	± 5.35	7.17
	6	13.8	± 3.32	2.75
	8	13.2	± 3.63	3.3
	10	12.0	± 4.44	2.96
	12	12.0	± 3.65	3.34
Fallow field (density 2)	2	23.3	± 6.89	11.9
	4	21.1	± 5.2	6.75
	6	19.3	± 3.25	2.64
	8	18.2	± 2.49	1.56
	10	16.7	± 2.90	2.10
	12	16.4	± 3.12	2.43
Stubble field	2	19.0	± 9.64	23.2
	4	27.0	± 4.39	4.82
	6	30.1	± 11.5	33.10
	8	30.7	± 9.06	20.5
	10	26.4	± 2.99	2.23
	12	25.9	± 4.21	4.44

TABLE 4.14. MEAN MOISTURE CONTENT,* 95% CONFIDENCE LIMITS, AND VARIANCE OF THE FIELD CONDITIONS.

Field Condition	Depth (in.)	Mean Moisture Content %	95% Confidence Limits	Variance σ^2
Fallow field density 1	2	30.6	± 1.91	0.916
	4	33.5	± 2.27	1.29
	6	33.8	± 2.59	1.68
	8	30.8	± 3.59	3.22
	10	28.9	± 4.77	5.7
	12	27.8	± 4.46	4.98
Fallow field density 2	2	29.3	± 1.66	0.692
	4	31.9	± 1.3	0.424
	6	32.4	± 1.79	0.804
	8	30.7	± 2.93	2.14
	10	28.0	± 2.85	2.30
	12	26.1	± 3.78	2.56
Stubble field	2	15.0	± 3.25	2.64
	4	17.0	± 2.25	1.26
	6	17.2	± 1.88	0.883
	8	17.3	± 1.85	0.888
	10	16.4	± 2.57	1.64
	12	15.4	± 3.77	3.55

* Gravimetric method.

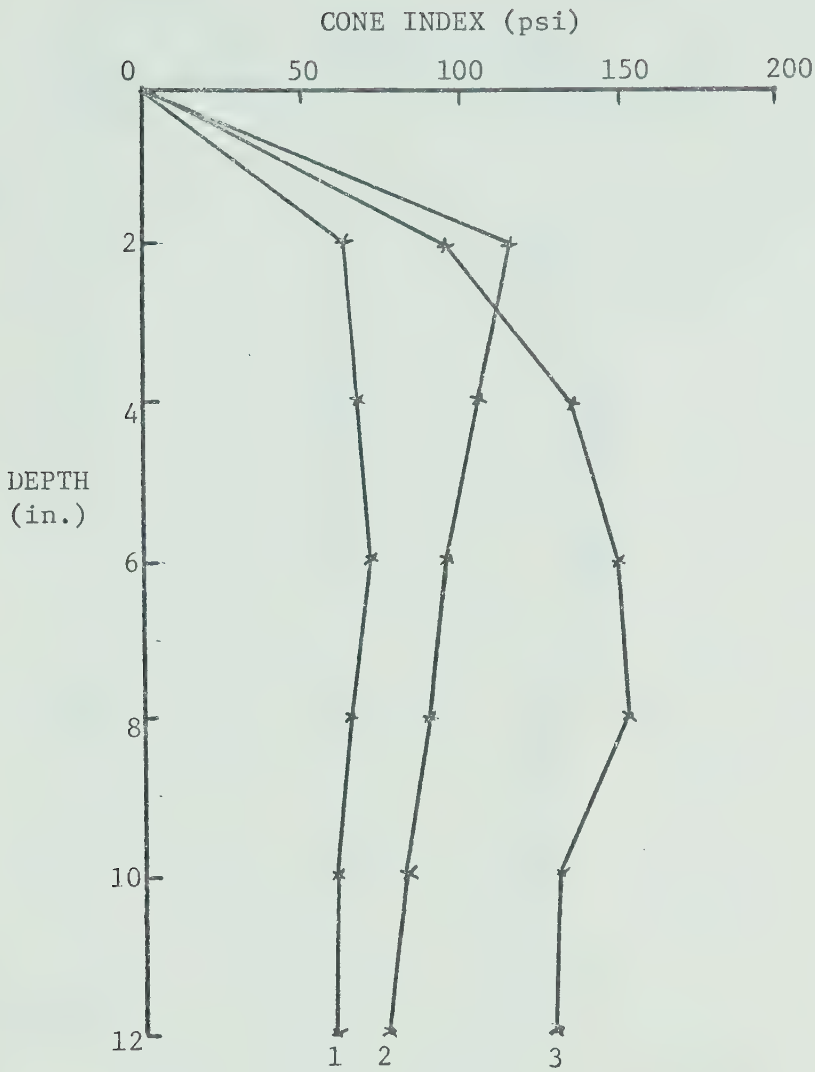


Figure 4.10: Mean penetrometer curves for the three test fields.
1. Fallow field density 1.
2. Fallow field density 2.
3. Stubble field.

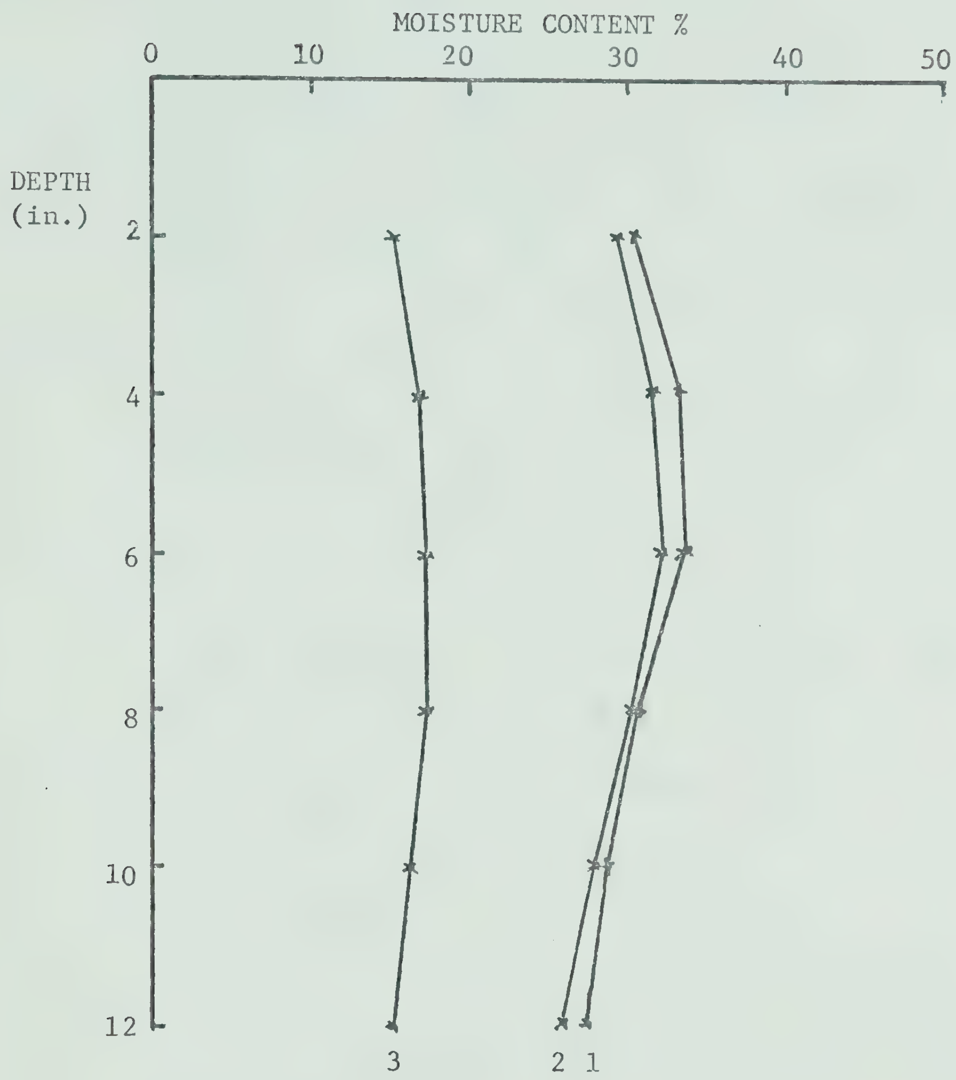


Figure 4.11: Mean moisture content curves for the three test fields.
1. Fallow field density 1.
2. Fallow field density 2.
3. Stubble field.

4. Oxygen diffusion rate: O.D.R. equipment has already been described in section 3.2.2. On both the fallow fields, at each selected location ten O.D.R. measurements were obtained at the seeding depth of two inches below the soil surface. The fallow field of density 1 gave an average O.D.R. of 40.66 $\times 10^{-8}$ gm/cm^2-min. and the average for fallow field of density 2 was 38.75 $\times 10^{-8}$ gm/cm^2-min. However, the measurements could not be made for the stubble field. The high penetration resistance of the stubble field made it impossible to insert the platinum microelectrode in the soil.

5. Shear strength: Soil shear strength was determined with a Cohron sheargraph. The two shear strength components c and Ø were obtained from the graph of shear stress versus normal stress for both the fallow fields, where c is the cohesion in psi and Ø is the angle of internal friction in degrees. It was difficult to insert the shear head in the stubble field. Therefore,it was not possible to determine the shear strength of the stubble field. The results are given in table 4.15.

TABLE 4.15. c and Ø VALUES FOR FALLOW FIELD OF DENSITY 1 AND 2.

Field	Cohesion (c) psi	Angle of Internal Friction (Ø) degrees
Fallow field (density 1)	1.2	35.5
Fallow Field (density 2)	1.2	40.3

As indicated by Schafer et al (21) the torsion test can be used in the field to obtain good estimates of the soil shearing strength parameters, c (cohesion), and ϕ (angle of internal friction). Portability and ease of measurement make the Cohron sheargraph a valuable instrument for the measurement of c and ϕ.

No attempt has been made here to correlate the depth load characteristics with physical properties of soil. Data over a wide range of density/moisture levels is required before an intelligent correlation can be established. The soil properties measured could be used only to characterize the soil.

Chesness et al (5) derived, in the laboratory, a prediction equation for cone index as a function of depth, bulk density and soil moisture content on remolded samples for a given soil texture; and verified the applicability of the derived equation with the field measurements. The authors concluded that the remolded samples did not exhibit the same soil strength or resistance to penetration as in-situ soil. To obtain any field predictive relationships between penetration resistance and soil strength the parameters must be evaluated in in-situ soil. Furthermore, the parameters of bulk density and moisture content were not sufficient to describe penetration resistance in the field.

Chapter 5

SUMMARY AND CONCLUSIONS

5.1 Summary.

The depth/load characteristics of double disk and rolling disk coulters of size ranging from 9 1/2 in. to 18 in. were obtained in the present study. The performance of a 17 in. notched coulter has also been evaluated.

The analysis of the field runs carried out under different load conditions indicated that the depth/load relationship was not significantly affected by load conditions. However, the maximum load that can be applied to a coulter unit and consequently the maximum obtainable depth could be increased moderately by putting extra load on the seed drill or by decreasing the number of units.

The experiments under static conditions gave less depths of penetration than dynamic conditions for a given load on the coulter unit. This also suggests that greater depths can be achieved at higher operational speeds. This effect is more pronounced for small sized coulters. However, the foregoing generalization may not hold beyond a certain speed of operation.

Comparison of the depth performance of the various coulters indicated that the 17 in. notched coulter is distinctly superior to the other coulters particularly in the strawed and stubbled fields. The other relevant factors regarding the coulter performance are its distance from the double disk, straw collection and the maximum load that can be applied on the coulter units. Although a firm conclusion cannot be established because of the unavailability of the depth/load characteristics of smaller sized

notched coulters, a notched coulter of size 14 - 15 in. should be satisfactory for the usual field conditions encountered under minimum tillage. A similar conclusion was also drawn from the analysis of the maximum obtainable depth from the joint coulter and double disk unit.

5.2 Recommendations for further work.

1. An arrangement for the continuous recording of the depth would indeed be very useful. With the continuous trace of both the load and the depth available, it would be easy to pick a sample point at any instant in time by merely reading the depth and the load from the traces. This would avoid cumbersome averaging of the load from the trace through the use of the planimeter. Furthermore, it would ensure greater accuracy and more representative readings. This could also make possible the use of more than one strain-gauged unit in the seed drill.

   Higher speeds could also be used. It would also cut down the total experimental time that is required in taking the depth measurement by at least 30%.

2. Depth/load relationships at the various operating speeds, moisture levels, and straw levels would be very desirable.

3. The depth performance of several different types of furrow openers with or without the coulter attachment is needed before an investigation into the field of minimum-tillage can be considered complete. The depth performance along with other operating characteristics such as collecting of straw, distance between coulter and the opener, maximum load that can be applied to the units, etc. should be determined. An optimal

practical coulter will be the one that offers maximum capacity (number of units x speed) for a given input of power while still meeting the satisfactory depth requirements.

Chapter 6

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APPENDICES

APPENDIX A: PLATINUM ELECTRODE AREAS DETERMINED IN A THREE PERCENT BENTONITE SOLUTION.

Electrode Number	Area (cm^2)
1	.0874
2	.079
3	.083
4	.083
5	.0916
6	.0762
7	.0880
8	.0766
9	.0840
10	.0897
11	.0900
12	.0855
13	.0810
14	.0855
15	.0902
16	.073
17	.093
18	.0865
19	.0780
20	.1020
21	.0910
22	.0860
23	.0950

Method: Area of electrode number 24 (standard electrode) was determined as .084 cm^2 using a micrometer to measure the diameter. Then the areas of the remaining electrodes were calculated from the ratio of currents read from O.D.P. apparatus.

$$\text{Area of unknown electrode} = \frac{\text{area of standard electrode}}{\text{current } (\mu a) \text{ of standard electrode}}$$

$$\times \text{ current } (\mu a) \text{ of unknown electrode.}$$

To measure the current readings a 3% Bentonite solution was prepared. The solution was thoroughly stirred with a mechanical stirrer to suspend all particles, and poured into a pan containing the electrodes. The solution was allowed to stand for 5 minutes. A potential of 0.65 volts was applied to all electrodes and current readings were recorded for each electrode (after 10 minutes).

APPENDIX B

PROG 'LINM' CMPUTES THE PARAMETERS ESTIMATES VARIANCE,AND 95 PERCENT CONFIDENCE LIMITS FOR LINEAR MODELS

```
      ∇LINM[⎕]∇
    ∇ LINM;N;M;A;C95;I
[1]   N←ρY
[2]   M←ρX[1;]
[3]   A←⌹(⍉X)+.×X
[4]   B←A+.×(⍉X)+.×Y
[5]   ER←Y-X+.×B
[6]   SS←+/ER*2
[7]   VAR←SS÷(N-M)
[8]   C←VAR×A
[9]   'PARAMETERS :      ';B
[10]  I←0
[11]  C95←Mρ0
[12] LAB:I←I+1
[13]  C95[I]←2×C[I;I]*0.5
[14]  →LAB×⍳I<M
[15]  '95 PCNT LIMITS : ';C95
[16]  'VAR : ';VAR
[17]  'VAR-COVAR : ';C
[18]  'NORMAL ERRORS : ';ER÷VAR*0.5
    ∇
```

PROG 'MGT' USING MARQUARDT'S ALGORITHM FOR NON LINEAR MODELS

```
∇MGT[⎕]∇
∇ MGT;S1;S2;D1;D2;G;I;IL;IT;B1;B2;BB;C95;PHI1;PHI2;D;ER;A;STD
[1]   LAM←1
[2]   M←⍴B
[3]   N←⍴Y
[4]   IT←0
[5]   I←(⍳M)∘.=⍳M
[6]  LBB:→⍳0
[7]   PHI←B FUCN LM
[8]   X←B DSNM LM
[9]   G←(⍉X)+.×(Y-PHI)
[10]  SS←(⍉(Y-PHI))+.×(Y-PHI)
[11]  A←((⍉X)+.×X)
[12]  D←I
[13]  IL←0
[14] LAS:IL←IL+1
[15]  D[IL;IL]←A[IL;IL]*¯0.5
[16]  →LAS×⍳IL<M
[17]  A←D+.×A+.×D
[18]  D1←(D+.×(⌹(A+LAM×I))+.×D)+.×G
[19]  D2←(D+.×(⌹(A+(LAM÷NU)×I))+.×D)+.×G
[20]  B1←B+D1
[21]  B2←B+D2
[22]  BB←B
[23]  B←B1
[24]  PHI1←B FUCN LM
[25]  B←B2
[26]  PHI2←B FUCN LM
[27]  S1←(⍉(Y-PHI1))+.×(Y-PHI1)
[28]  S2←(⍉(Y-PHI2))+.×(Y-PHI2)
[29]  →THRE×⍳((|(+/((BB-B1)÷BB)))<1E¯5)
[30]  →ONE×⍳S2≤SS
[31]  →TWO×⍳S1>SS
[32]  B←B1
[33]  SS←S1
[34]  →LBC
[35] ONE:LAM←LAM÷NU
```

```
[36]  →ONE1×⍳S2≤S1
[37]  B←B1
[38]  SS←S1
[39]  →LBC
[40] ONE1:B←B2
[41]  SS←S2
[42]  →LBC
[43] TWO:LAM←LAM×NU
[44]  B←BB
[45] LBC:B,SS
[46]  →LBB
[47] THRE:→FOUR×⍳SS<S1
[48]  X←B DSNM LM
[49]  SS←S1
[50]  ER←Y-PHI1
[51]  →FIVE
[52] FOUR:B←BB
[53]  ER←Y-PHI
[54] FIVE:'PARAMETERS : ';B
[55]  VAR←SS÷N-M
[56]  C←VAR×(⌹(⍉X)+.×X)
[57]  C95←B
[58]  I←0
[59] LST:I←I+1
[60]  C95[I]←2×(C[I;I]*0.5)
[61]  →LST×⍳I<M
[62]  '95 PCNT LMT: ';C95
[63]  'VARIANCE : ';VAR;'STD DEV: ';STD←VAR*0.5
[64]  'VAR-COVAR: ';C
[65]  'NORMAL ERRORS:';ER÷STD
```

PROG 'DSNM' COMPUTES THE DERIVATIVES OF THE

MODEL FOR 'MGT'

```
      ∇DSNM[⎕]∇
    ∇ X←B DSNM LM;M
[1]    M←ρB
[2]    X←(⍳N)∘.=⍳M
[3]    →ONE×⍳LM=1
[4]    →TWO×⍳LM=2
[5]    →THRE×⍳LM=3
[6]    →FOUR×⍳LM=4
[7]    →SEVEN×⍳LM=7
[8]    →SIX×⍳LM=6
[9]   ONE:X[;1]←PHI÷B[1]
[10]   X[;2]←PHI×2×⍟(((1-XA)*1.5)÷NE)
[11]   →TEN
[12]  TWO:X[;1]←PHI÷B[1]
[13]   X[;2]←-PHI×L÷(1+B[2]×L)
[14]  TEN:→⍳0
    ∇
```

PROG 'FUCN' COMPUTES THE MODEL PREDICTION FOR MGT

```
      ∇FUCN[⎕]∇
    ∇ PHI←B FUCN LM
[1]    →FOUR×⍳LM=4
[2]    →THRE×⍳LM=3
[3]    →TWO×⍳LM=2
[4]    →SIX×⍳LM=6
[5]    →SEVEN×⍳LM=7
[6]   ONE:PHI←B[1]×((((1-XA)*1.5)÷NE)*2×B[2])×(((XS-1)÷XS))
[7]    →FIVE
[8]   TWO:PHI←B[1]×L÷(1+B[2]×L)
[9]   FIVE:→⍳0
    ∇
```